United States
Department of
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Agricultural
Research
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ARS-64

December 1987

Economic Importance and Biological Control of *Lygus* and *Adelphocoris* in North America

ABSTRACT

Hedlund, R.C., and H.M. Graham, editors. 1987. Economic Importance and Biological Control of *Lygus* and *Adelphocoris* in North America. U.S. Department of Agriculture, Agricultural Research Service, ARS-64, 95 pp.

This publication contains a series of reports on the status of *Lygus* spp. and *Adelphocoris lineolatus* (Goeze) as pests of several crops in North America. Past efforts at controlling these pests by predaceous and parasitic arthropods are reviewed and some new work is documented. In addition, there are sections on the taxonomy of the pests and euphorine braconids that parasitize them. Recommendations are made for future work on the biological control of these pests.

KEYWORDS: *Adelphocoris* spp., biological control, Braconidae, Diptera, Hemiptera, Hymenoptera, Ichneumonidae, *Lygus* spp., Mermithidae, Miridae, Mymaridae, Nematoda, parasitic insects, predaceous insects, Tachinidae.

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Economic Importance and Biological Control of *Lygus* and *Adelphocoris* in North America

Editors

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CONTENTS

STUDIES ON THE BIOLOGICAL CONTROL OF PLANT BUGS (HETEROPTERA: MIRIDAE): AN INTRODUCTION AND HISTORY, 1961-83

By Jack R. Coulson[1]

This brief survey of studies on the biological control of plant bugs (Heteroptera: Miridae) presents an overview of the subject as an introduction to this publication. More detailed accounts of some of the activities noted here, especially the more recent studies, can be found in other sections of this publication.

The targets of these biological control activities have been primarily species of the *Lygus* complex (Mirinae, tribe Mirini) in the United States and Canada, including several destructive pests of such crops as cotton, alfalfa, many vegetables, and deciduous fruits. Within the complex are the tarnished plant bug, *Lygus lineolaris* (Palisot), the most serious of the mirid pests throughout North America, and *L. hesperus* Knight and *L. elisus* Van Duzee, major pests in the Western United States. Two other species of the subfamily Mirinae, the meadow plant bug, *Leptopterna dolabrata* (L.) (tribe Stenodemini), and the alfalfa plant bug, *Adelphocoris lineolatus* (Goeze) (tribe Mirini), have been more recent targets of biological control studies. Of these target pests, only *A. lineolatus* is clearly an introduced species in North America, being first recorded in 1917 in Nova Scotia (Knight, 1922). It is unclear whether *L. dolabrata* is native or introduced; whether it is truly Holarctic is open to conjecture (Slater, 1974).

This summary is mainly concerned with "classical" biological control activities, that is, the importation of foreign natural enemies. It has been compiled from literature and unpublished reports and correspondence in the files of the Beneficial Insects Laboratory, as of 1982, the official Agricultural Research Service (ARS) Biological Control Documentation Center. This summary is not a comprehensive survey of the literature on the subject; Graham et al. (1984) published a bibliography of the worldwide literature on the *Lygus* complex. Details of the activities briefly discussed here are in other sections of this publication or can be obtained from References Cited in this article. Except for one early attempt to utilize a fungus to control a mirid pest (Dustan, 1923), all studies on the biological control of plant bugs in North America began in the 1960's. These activities are discussed in 5-year segments in the following account. Summaries of the Canadian studies were published by Craig and Loan (1984).

1961-65. Studies were undertaken by ARS at Riverside, Calif., in 1961 with field surveys in southern California and other Western States to determine the complex of natural enemies of *Lygus hesperus* and *L. elisus* in alfalfa. In 1962-64, similar surveys of natural enemies of *L. lineolaris* in alfalfa were conducted by ARS at Moorestown, N.J., in New Jersey and Pennsylvania. In 1963-65, several shipments of the native hymenopterous parasites *Peristenus pallipes* (Curtis) and *P. pseudopallipes* (Loan) (Braconidae) were shipped from New Jersey collections for study and release (1964 only) in California, where the species did not occur. During this period, specimens of a dipterous parasite, *Alophorella* sp. (Tachinidae), were also sent from New Jersey but not released. Parasitism of lygus bugs in all areas surveyed was found to be low.

Limited surveys of natural enemies of mirids were also conducted in France by the ARS European Parasite Laboratory (EPL) from 1962 to 1965. One shipment of "*Euphorus pallipes*" cocoons from *Lygus rugulipennis* Poppius was sent from France to California in 1963, but no adult parasites emerged. During this same period, Canadian workers also conducted research on mirid pests and their natural

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enemies. Results of the studies in the Eastern and Western United States, Europe, and Canada were published by Craig (1963), Adlung (1964), Loan (1965), Clancy and Pierce (1966), and Streams et al. (1968). Late in this period, the Commonwealth Institute of Biological Control (CIBC) station in Switzerland conducted a literature survey of European mirids and their natural enemies and produced an unpublished, undated report (Carl, 1964 (?)). This report concluded that little was known of European natural enemies of mirids.

1966-70. Studies of *L. lineolaris* in the Eastern United States continued in 1966-68 in Connecticut under an ARS-supported research grant (University of Connecticut, Storrs) (Streams et al., 1968; Shahjahan and Streams, 1973). Studies also continued in Canada, including the initiation of critically needed taxonomic studies of the braconid parasites of mirids (Loan, 1970).

In March 1966, a 5-year Special Foreign Currency (PL-480) Project (E21-ENT-11) was undertaken with the Institute of Ecology of the Polish Academy of Sciences, Warsaw. The purposes of this project were to study the role of braconid parasites in the regulation of populations of *L. rugulipennis* and other *Lygus* species, primarily in rye and potato crops, to develop techniques for rearing the parasites, and to define the parasites taxonomically. A complex of three *Peristenus* species was found that required later taxonomic clarification. In 1968-70, several shipments of these braconid parasites were made to the United States for study and propagation. Bilewicz-Pawińska (1969) published a report of these early studies.

A "Lygus Bug Research Workshop," sponsored by the University of California, Davis, was held at Davis in March 1969. Unfortunately the proceedings of this workshop were never published. During the workshop, progress of the Polish studies was reported by ARS. This resulted in interest in importing Polish parasites for release against *Lygus* spp. in cotton at ARS stations in Tucson, Ariz., and Stoneville, Miss. Shipments of a Polish *Peristenus* sp. (*rubricollis* (Thomson), according to W.H. Day, ARS, Newark, Del., in litt., Sept. 26, 1983) were made to Arizona in 1970 through ARS quarantine facilities at Moorestown, N.J., and were released at four locations in Arizona. This was the first exotic mirid parasite to be released in North America. Also, studies of the indigenous parasites of *Lygus* spp. were begun in Arizona (for example, see Stoner and Surber, 1969). Because of the increased interest in exotic parasites, work on lygus bugs was reinitiated in 1970 at the ARS European Parasite Laboratory (EPL) in France.

1971-75. The Polish project was terminated in March 1971 and resulted in an unpublished final report by Bilewicz-Pawińska [1971] and several publications on the field studies and on the biologies and culture of the parasites (for example, Bilewicz-Pawińska, 1974a; Bilewicz-Pawińska and Pankanin, 1974). Taxonomic studies in Canada clarified the identity of the braconid parasites of mirids in North America and in Europe (Loan and Bilewicz-Pawińska, 1973; Loan 1974a, 1974b). In March 1973, a new 4-year PL-480 project (PL-ARS-18) was undertaken with the Polish Institute of Ecology to further study the role of the *Peristenus* spp., now known as *P. digoneutis* Loan, *P. rubricollis* (Thomson), *P. stygicus* Loan, and *P. stenodemae* Loan, in reducing populations of the plant bugs *Lygus rugulipennis*, *Adelphocoris lineolatus*, and *Stenodema virens* (L.) in crop environments. Results of these studies are in an unpublished final report by Bilewicz-Pawińska [1977d] and in several publications that appeared near or after the conclusion of the project (see below). Small numbers of *Peristenus* cocoons were shipped to the United States in 1974 and 1975 and a larger number in 1976 (see below).

In 1971, the new braconid, described as *Peristenus stygicus* (Loan and Bilewicz-Pawińska, 1973), was recovered from the mirine plant bug *Polymerus unifasciatus* (F.) during EPL surveys in Turkey. EPL later found this species and the other two previously found in Poland,

P. rubricollis and P. digoneutis, from Lygus spp. nymphs in France (Drea et al., 1973). EPL began shipments of these species to the United States in 1971 to the ARS quarantine facility of the Beneficial Insects Research Laboratory (BIRL) (Moorestown, N.J., 1971-73; Newark, Del., 1973+). Two of the species, P. digoneutis and P. stygicus, were cultured on L. rugulipennis at EPL.

During this period, work at BIRL consisted primarily of receiving Peristenus cocoons from overseas in quarantine, overwintering the diapausing cocoons, and shipping emerged adult parasites to Arizona, California, Mississippi, Texas, and Canada for culture, study, and release. However, a few specimens of P. stygicus from France and Turkey and of P. digoneutis from France were released against Lygus spp. in alfalfa in New Jersey in 1972 and 1973, respectively.

In 1971-72 and 1974, shipments of P. stygicus from both Turkey and France were sent from BIRL to the Department of Entomology, University of California, Riverside, where the species was cultured. In 1972-73, over 20,000 P. stygicus specimens from this culture were released against Lygus hesperus in alfalfa in the San Joaquin Valley of California. Although populations of the parasites were small (Van Steenwyk and Stern, 1976, 1977), the species was recovered in the release fields at least through 1978. Small numbers of French P. digoneutis were also sent to California for culture from 1971 to 1974, and this species was released in the field there in 1972. Attempts to culture the French P. rubricollis sent to California in 1975 were unsuccessful.

In 1971-72, P. stygicus from Turkey and France was also sent to the ARS Tucson, Ariz., laboratory, where it was cultured (Butler and Wardecker, 1974) and released against Lygus spp. in cotton. Adults of P. rubricollis from Poland also were released in Arizona in 1971. That same year a shipment of French P. digoneutis specimens was sent to Arizona from BIRL for culture. The Arizona laboratory also received P. stygicus from the culture in California during this period. No parasites were recovered at any Arizona release site in 1972 surveys.

In 1971, Turkish P. stygicus was sent to Texas A&M University by BIRL and released against Lygus spp. in Texas alfalfa.

And in 1975, adults of P. stygicus from the California culture were received, cultured, and released by Mississippi State University personnel at several locations in Mississippi against Lygus lineolaris in wild host plants. Recovery attempts in 1976 were unsuccessful. Adults of the French P. digoneutis were also sent to Mississippi State University by BIRL in 1975, but attempts to culture the species were unsuccessful. During this period, the ARS Stoneville, Miss., laboratory completed surveys of lygus bug natural enemies in Mississippi (Scales, 1973).

Improvements in Lygus culture techniques were made in both Mississippi and Arizona (Parrott et al., 1975; Bryan et al., 1976).

MacDonald College in Quebec, Canada, also received P. stygicus from the University of California culture during this period for culture and study, but no releases were made. Broadbent (1976) expressed the need for parasite biotypes that might be better adapted to the climatic conditions of Quebec. A few P. digoneutis specimens also were received at MacDonald in 1973, 1976, and 1977 and P. stygicus in 1976-77 from the ARS quarantine facility in Delaware.

In 1974, the CIBC station in Pakistan issued an unpublished memorandum on the possibilities of biological control of Lygus spp. (Khan et al., 1974). Though not as detailed as the later (1979) CIBC report (see below), this memorandum resulted in negotiation by ARS of a 3-year PL-480 project with the CIBC Pakistan Station for a survey of natural enemies of mirid plant bugs in Pakistan, Afghanistan, Iran, Turkey, and China. This project was undertaken in December 1975.

In 1975, an important taxonomic report clarifying the status of Lygus spp. in North America was published (Kelton, 1975).

1976-80. The PL-480 project in Poland was terminated in March 1977. A final shipment of 200 Polish parasite cocoons was sent to the BIRL quarantine facilities in Delaware in 1976. Publications from the project include Bilewicz-Pawińska, 1973, 1974b, 1976a, 1976b, 1977a, 1977b, 1977c, and Bilewicz-Pawińska and Kamionek, 1973. See also the unpublished final report by Bilewicz-Pawińska [1977d].

In 1976, a second lygus bug workshop, organized by members of the Department of Entomology, University of Idaho, was held at the XV International Congress of Entomology in Washington, D.C. Proceedings of this workshop on host plant-lygus bug interactions were published (Scott and O'Keeffe, 1976).

EPL collections in Europe in 1976-77 were expanded to France, Germany, Hungary, Austria, and Denmark, but they were confined to France and Austria in 1978 and only to France in 1979. Collections were made of Lygus rugulipennis, L. pratensis (L.), and Adelphocoris lineolatus. Shipments of the three Peristenus spp., primarily from France and Austria, were made from 1976 to 1979, and a fourth species of Peristenus, later described as P. adelphocoridis Loan (Loan, 1979), was recovered from A. lineolatus; P. rubricollis and P. digoneutis were also found on this host, the latter species only rarely. A nematode parasite was found in Lygus spp. in 1977; a nematode had also been found earlier in the Polish studies (Bilewicz-Pawińska and Kamionek, 1973). Cultures at EPL were discontinued during 1978 in favor of direct shipment to U.S. quarantine (BIRL) of large numbers of parasite cocoons directly from field collections. In 1980, efforts were renewed at EPL to obtain parasites from collections of Lygus and Adelphocoris in France and Austria. They were destined for the BIRL program in New Jersey for releases against plant bug pests of alfalfa. Parasites from EPL collections from the same hosts in Spain were directed to the revived importation program at the ARS laboratory at Tucson, Ariz., for releases against Lygus pests of cotton.

At BIRL, laboratory rearing methods for the parasites were studied in 1976-77, and the three Lygus parasites were released in Delaware alfalfa fields during 1976-78. In 1977, releases of the parasites were begun in New Jersey alfalfa fields; these releases continued in 1978-80, targeted against Lygus lineolaris, A. lineolatus, and Leptopterna dolabrata in alfalfa at two northern New Jersey study sites. Though a few recoveries of Peristenus stygicus and P. rubricollis were made in Delaware and New Jersey, apparently none of the parasites were established. In 1980, a tachinid parasite of lygus bugs, Alophora obesa (F.), from EPL collections in Austria, was released in Delaware.

European parasites also were shipped by BIRL to Mississippi State University in 1976-78 for study, culture, and release (P. stygicus and P. digoneutis; attempts to culture the latter and P. rubricollis failed; see Hormchan, 1977). The same species were sent to MacDonald College in Quebec for culture and study in 1976-77 (see above). The need for determining the host ranges of the mirid parasites was discussed by researchers in 1977-78, partially as a result of the 1976 workshop. Consequently, shipments were made to the ARS laboratory in Yakima, Wash., in 1978 and to Texas A&M University, College Station, in 1976-79 for such studies. The culture in Washington was unsuccessful, but testing of P. stygicus in Texas was completed by Porter (1979), and some adults of this species were released in the State in 1979. In 1979, European Peristenus cocoons were sent to the ARS laboratory at Stoneville, Miss., and P. digoneutis and P. stygicus were released in that State against L. lineolaris in wild mustard. The P. stygicus specimens from the 1980 EPL collections in Spain were sent to the ARS laboratory in Tucson, Ariz. A healthy culture was initiated,

and as a result mass releases of this species against Lygus spp. in alfalfa were begun in Arizona in 1980.

During this period, scientists of Agriculture Canada's Research Station at Saskatoon, Saskatchewan, obtained European parasites for release against Lygus and Adelphocoris in alfalfa seed crops of Canada's Western Provinces. Research at Saskatoon had begun in 1975 with a survey of nymphal parasites of Lygus in the area. The CIBC station in Switzerland began surveys and collections in 1977 in Switzerland, France, Germany, and Austria. Cocoons of Peristenus were shipped to Canada in 1977-79, primarily from L. rugulipennis. Adelphocoris lineolatus was rare during the CIBC surveys. In 1980, collections were concentrated on Adelphocoris in Austria and Germany; about 500 cocoons from this host were sent to Canada in 1980. Between 1978 and 1980, a total of 1,720 P. digoneutis and 64 P. stygicus adults from the CIBC collections were released into Lygus populations in alfalfa seed fields in Saskatchewan and Alberta; in 1980, 49 P. rubricollis and 76 P. adelphocoridis were released against A. lineolatus (Craig and Loan, 1984). All recovery attempts were negative.

The CIBC Pakistan Station carried out studies, explorations, and collections of mirids and their natural enemies from December 1975 through November 1978 under the PL-480 project PK-ARS-91. These studies were conducted in Pakistan, India, Iran, Turkey, and Indonesia, the last in lieu of China, in which travel approval was never obtained. Several mirid species previously unknown in Pakistan were found. Parasites were extremely rare in Pakistan; only egg parasites were found on Lygus gemellatus (Herrich-Schaeffer) and Adelphocoris lineolatus. No Lygus spp. were found in the areas surveyed in India; 12 species of other mirids were collected. About 25,000 adults and nymphs of 19 mirid species were collected in Iran, and 14,500 specimens of 35 species were collected in Turkey. No parasites were recovered from any of the collections in India, Iran, and Turkey. Two species of mymarids parasitized 55 percent of the eggs of Lygus spp. in Indonesia. No parasites were recovered from the nymphal or adult mirids collected during these studies. Predators of Lygus spp. were also recorded, the most important of which was Nabis ferus L. (Heteroptera: Nabidae) (CIBC, 1981).

In 1979, CIBC published another report on the possibilities for biological control of lygus bugs (CIBC, 1979), noting, among others, studies of parasites of lygus bugs in East Africa conducted by scientists in the 1940's. As a partial result of this report, a 3-year cooperative agreement was negotiated in 1980 by ARS at Tucson, Ariz., with scientists of Texas A&M University, Dallas, for a survey and collection of plant bug parasites in Africa that might be useful introductions against Lygus spp. in cotton in the Southern United States.

Other activities during this period included the initiation in June 1978 of a 4-year (later extended to 5-year) PL-480 project, EG-ARS-83, at the University of Assiut in Egypt to search for natural enemies of Lygus spp. and related mirids in that country for possible introduction into the United States. Progress during the first year of the project included a survey of mirids and their predators, a seasonal and host plant study of Taylorilygus pallidulus (Blanchard), recovery of an egg parasitoid from T. pallidulus, and initiation of a bibliography of lygus bug literature (Graham et al., 1984). A bibliography of the genus Lygus was published in 1980 in Idaho (Scott, 1980, 1981).

In 1980, a survey of mirids and their natural enemies in cotton and wild host plants in the Transcaucasian area of the Soviet Union was proposed under the U.S.-U.S.S.R. Environmental Agreement. However, because of political developments, the proposal was not implemented.

In view of the many exploration and importation activities for lygus bug biological control, and the large number

of U.S. locations and scientists interested in studying and releasing exotic parasites, a Coordinating Subgroup on Biological Control of Lygus and Other Mirids, under the ARS Working Group on Natural Enemies, was established by ARS for a 3-year period in June 1980. The objectives of this subgroup were to (1) assist in planning for foreign exploration and collections and for quarantine receipt of natural enemies in the United States; (2) help expedite research on testing and propagation of introduced natural enemies and their dissemination to interested Federal and State scientists for study and release; (3) promote adequate exchange of information; and (4) coordinate the evaluation of field releases and reporting of the results. The first meeting of the subgroup was held in July 1980 at Texas A&M University facilities at Dallas.

1981-83. During this period, overseas explorations and studies were conducted in Europe and in Africa. The EPL concentrated on obtaining nymphal parasites of Lygus spp. from southern Europe for release against Lygus spp. in cotton by the ARS laboratory in Arizona, and of Lygus and Adelphocoris from more northern Europe for release against these bugs in alfalfa by the ARS in Delaware.

The parasites emerging at BIRL in 1981 from cocoons collected in 1980 by EPL included Peristenus digoneutis and a small number of P. rubricollis from France and Austria, but no P. adelphocoridis. There was no parasite emergence in 1981 from the host material collected in Spain in 1980.

Collections of Lygus and Adelphocoris spp. were made in 1981-83 by EPL in Austria, France, Spain, Italy, Greece, and Hungary. Some of the Peristenus cocoons from these collections were sent immediately to BIRL for overwintering. Others were held at EPL for overwintering, and the adult parasites that emerged were shipped the year following collection. All four European species of Peristenus were included in the shipments to BIRL. EPL personnel also prepared a large number of mirid specimens from these field studies for taxonomic study at the ARS Systematic Entomology Laboratory at Washington, D.C.

The objectives at BIRL during 1981-83 concerned the quarantine clearance and shipment of P. stygicus from southern Europe to the ARS laboratory in Arizona for culture and release, and the release of European parasites to attempt establishment on and reduce the abundance of plant bugs (Lygus lineolaris, Adelphocoris lineolatus, and Leptopterna dolabrata) in alfalfa in the Middle Atlantic States.

Spanish and Greek P. stygicus specimens were forwarded by BIRL to the Arizona laboratory in 1982 and 1983. Also, some specimens of the native Leiophron uniformis (Gahan) (Hymenoptera: Braconidae) from Lygus lineolaris in Delaware were sent by BIRL to Tucson in 1981 for study of their effectiveness against Lygus hesperus nymphs in Arizona.

About 1,450 P. digoneutis, 100 P. rubricollis, and 28 P. stygicus females were released against L. lineolaris during these 3 years at BIRL's New Jersey release sites, and 48 P. adelphocoridis females were released against A. lineolatus in 1983. No recoveries were made of any of the species in 1981-82; one male P. digoneutis was recovered in 1983. A study of field parasitism of L. lineolaris, A. lineolatus, and Leptopterna dolabrata by native parasites in New Jersey yielded only Peristenus pallipes. Host acceptance tests with the European parasites and the three target plant bug species were also conducted in the laboratory at BIRL during 1981-83.

The objectives of the studies conducted at the ARS Biological Control of Insects Laboratory at Tucson during these years continued to be to reduce populations of Lygus hesperus and other Lygus pests of cotton in the Southwest by introducing and augmenting releases of promising parasites. Successful laboratory cultures of Peristenus stygicus from Spain and Greece were established in 1980 and 1983, respectively; more parasites from Spain were received in 1982 and

1983. Mass releases from these cultures were conducted in alfalfa test plots near Tucson in 1981-83. There were no recoveries of the parasite in 1981, but peak field parasitism in 1982 and 1983 was 16.7 and 10.2 percent, respectively, during peak Lygus nymph populations in the season of release. When releases ceased in late summer, no further parasites were found, and there was no evidence of overwintering of P. stygicus in Arizona.

In 1982, P. stygicus specimens from the Arizona culture were sent to researchers at Texas A&M University at Dallas for release. No recoveries of the parasite were made at Texas release sites in 1982 or 1983.

Studies of the effectiveness of native parasites and predators of Lygus were also continued at the Arizona laboratory, including studies on the native nymphal parasite Leiophron uniformis and egg parasite Anaphes ovijentatus (Crosby and Leonard) (Hymenoptera: Mymaridae) (Graham et al., 1986). Also in 1983, the cooperative worldwide bibliography of literature concerning the Lygus complex, begun under the Egyptian PL-480 project in 1978, was completed (Graham et al., 1984).

Studies in Europe were also conducted by the CIBC station in Switzerland in 1981-83, with the objective of obtaining parasites of the alfalfa plant bug, Adelphocoris lineolatus, for release and establishment in alfalfa seed crops in midwestern Canada. Collections in Austria in 1981 resulted in shipment to Canada Agriculture quarantine facilities in Ottawa of 820 Peristenus cocoons from A. lineolatus. These cocoons yielded 103 P. digoneutis, 64 P. adelphocoridis, 13 P. rubricollis, and 3 P. stygicus adults and 9 of the hyperparasite Mesochorus sp. (Hymenoptera: Ichneumonidae). Efforts by CIBC in 1982-83 were concentrated on studies of the population dynamics of A. lineolatus and on developing improved collection and cocooning techniques to obtain greater quantities of P. adelphocoridis. Mass collections of this parasite in Austria for shipment to Canada were expected to be possible in the late summer of 1984.

Canadian studies continued at the research station at Saskatoon, Saskatchewan, with the objective of reducing populations of Lygus spp. and A. lineolatus in alfalfa seed crops in the Prairie Provinces. The fields in Saskatchewan and Alberta where Peristenus parasites were released during 1978-80 were monitored during 1981-82, but no introduced parasites were recovered. A total of 51 P. adelphocoridis adults from CIBC Austrian shipments were received in 1981 from the Ottawa quarantine station. They were released in alfalfa, but synchronization with the target Adelphocoris host was poor and no recoveries were expected. Adults of P. digoneutis were also received in 1981 and released against Lygus spp. In 1982, some of the cocoons of P. adelphocoridis from the CIBC Austrian collections were sent by the Ottawa quarantine station to BIRL for host acceptance tests.

Studies and explorations in Africa in 1981-83 were conducted in Egypt and several areas of subsaharan Africa.

Work at the University of Assiut in Egypt continued under the PL-480 project initiated in 1978. The objectives of this work continued to be to study the distribution, faunistic composition, seasonal abundance, and host ranges of Egyptian Heteroptera, particularly the Lygus complex, and to discover and study predators and egg and nymphal parasites of mirids in Egypt. The biological control related activities conducted during 1981-83 are summarized as follows: No nymphal parasites were recovered from Taylorilygus pallidulus or any other mirid in Egypt. An egg parasite, Telenomus sp. (Hymenoptera: Scelionidae), was found parasitizing up to 95 percent of T. pallidulus eggs in the Fayoum area, particularly on Matricaria chamomilla L., the favored host plant of T. pallidulus in that area. Studies were reported to be underway to determine whether other mirids also served as hosts of this egg parasite. Also, a worldwide bibliography of the Lygus complex started in 1978 was completed in 1983 (Graham et al., 1984).

Under the ARS-funded cooperative agreement with the Texas A&M University, Dallas, begun in 1980, three exploration trips to subsaharan Africa were conducted in 1981, 1982, and 1983. The several shipments of mirid parasites collected during those explorations were sent to the ARS Stoneville Research Quarantine Facility at Stoneville, Miss. The objectives of this agreement were to discover, evaluate, and introduce parasites of African mirids, particularly nymphal parasites, some of which were reported from earlier studies (Taylor, 1945; Nixon, 1946), that would attack Lygus pests of cotton in the Southwestern United States, and to determine if hosts of these parasites included predaceous mirids, particularly of the genus Deraeocoris.

In May 1981, nymphs of the brown wattle mirid, Lygidolon laevigatum Reuter, were collected from wattle, Acacia mearnsii De Wild., in Natal Province of the Republic of South Africa. Also, mirids of the genera Orthotylus, Taylorilygus, and Deraeocoris were collected from surrounding vegetation. Two hymenopterous egg and two nymphal parasites of Lygidolon were found and identified by the collector (M.F. Schuster) as, respectively, Chaetostricha and Telenomus spp. (Trichogrammatidae and Scelionidae), and Peristenus nigricarpus (Szepligeti) and P. praetor (Nixon) (Braconidae). Two shipments of the nymphal parasites were sent to the Mississippi quarantine facility (see below).

In 1982, an exploratory collection trip was made from January to March through Egypt, Sudan, Kenya, and the Republic of South Africa. Information collected during this trip indicated that both Peristenus nigricarpus and P. praetor were parasites of Taylorilygus and Lygidolon spp. from Sudan to South Africa and west to the Cape Verde Islands, and that there was another Peristenus parasite of the predaceous mirid Deraeocoris spp. that should be excluded from any shipments to the United States. Three shipments of parasites collected during the trip were sent to the quarantine facility in Mississippi.

In October 1983, explorations took place in Kenya, where collections were mainly of mirids from grain sorghum and lantana; collections in cotton were poor.

Parasite cocoons were obtained from Taylorilygus spp., and a shipment of parasitized nymphs and parasite cocoons was made to Mississippi.

Activities at the ARS Stoneville, Miss., location included quarantine receipt, clearance, and initial culture of the parasites received from Africa. The two 1981 shipments of nymphal parasites from South Africa were delayed in reaching Stoneville, and only three braconid parasites were received alive. No mating was observed and no parasitization of the Lygus lineolaris or L. hesperus offered as hosts was obtained. A total of 17 adult Peristenus praetor, 140 P. nigricarpus, and 10 Mesochorus hyperparasites emerged from the 3 shipments received from Africa in 1982. The remaining unemerged African cocoons were placed in cold storage, but no further emergence occurred when they were removed in 1983. The adult parasites obtained in 1982 were exposed to Lygus lineolaris nymphs (2-4 instar) resulting in 17 F_1 and 3 F_2 P. praetor progeny and 24 F_1 but no F_2 P. nigricarpus progeny. Unfortunately both colonies expired. Eight P. nigricarpus adults and an undescribed Leiophron sp. were recovered in quarantine from the 1983 African shipment. A small F_1 (10 adults) of P. nigricarpus was produced on L. lineolaris and a smaller F_2 (5 adults) on L. hesperus. No F_3 generation was produced.

Scientists at Stoneville also conducted a survey of mirids and their host plants and natural enemies in the Delta area of Mississippi and associated areas, and they sent a large number of mirid species and specimens to the ARS Systematic Entomology Laboratory (SEL) in Washington, D.C., for taxonomic study and deposit in the U.S. National Collection of Insects (Snodgrass et al., 1984a, 1984b). Some taxonomic studies were conducted in collaboration between scientists at SEL and the Department of Entomology, Oregon State University (see

the report in this publication by T.J. Henry and J.D. Lattin).

During 1981-83, efforts to establish cooperative arrangements for collections of mirids and their natural enemies in Morocco, Israel, and the People's Republic of China were unsuccessful.

In October 1983, a meeting of the ARS Coordinating Subgroup on Biological Control of Lygus and Other Mirids, established in 1980, was held at Beltsville, Md. At, and subsequent to, that meeting, plans for this publication were finalized. Summary information and several recommendations were prepared and submitted for consideration by the ARS National Program Staff, including further research on the taxonomy, biology, and rearing of mirids and their parasites; foreign exploration for and quarantine procedures for these parasites; and studies on their release, recovery, and evaluation.

This completes this summary of studies on the biological control of mirid plant bugs in North America. Despite over 13 years of efforts to establish exotic parasites of plant bug pests in North America, there is no evidence at this date that any have been established. However, much information on mirids and their natural enemies has been accumulated. Many research approaches remain to be explored, as discussed at the 1983 subgroup meeting noted here and in the last article of this publication. This summary and publication may therefore be considered only an interim report on the biological control of plant bug pests.

As noted in the introduction, this summary was prepared from several published references and many unpublished reports and correspondence on file at the Beneficial Insects Laboratory. Many of these documents have been prepared and provided by the authors of the reports in this publication, and the reader is referred to these reports for additional details.

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BIOLOGICAL CONTROL OF PLANT BUGS IN COTTON

By M.F. Schuster[1/]

DEFINITION AND HISTORY OF THE PROBLEM

Damage to cotton caused by the tarnished plant bug, *Lygus lineolaris* (Palisot), was first investigated shortly after damage caused by the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), was demonstrated by Reinhard (1926). Ewing (1929) reported that feeding of *L. lineolaris* caused swelling of internodes and petioles and abnormal branching. Subsequent studies by Ewing and McGarr (1933) showed that feeding of *L. lineolaris* and other mirids reduced retention of fruits by plants, whereas feeding of several leafhoppers had no effect on fruiting.

Mechanically debudding cotton to simulate plant bug damage increased the total number of buds produced by a plant (Hamner, 1941; Dunnam et al., 1943). Complete debudding until the third week of July in Mississippi did not significantly reduce yields of cotton when plots were protected in late season from boll weevils, *Anthonomus grandis* Boheman, and bollworms, *Heliothis zea* (Boddie) (Hamner, 1941). Late season protection of bolls, however, required extensive control measures for boll weevils and bollworms. Bolls produced late in the season were more often subject to early frosts, had increased incidence of boll rot, had reduced boll size, and produced less fiber of lower quality and value than earlier bolls.

Damage to cotton caused by *Lygus hesperus* Knight was dramatically shown by Wene and Sheets (1964). They reported that *L. hesperus* could kill seedling cotton, and that feeding damage to presquaring cotton resulted in deformed plants with reduced rates of squaring for 2 to 4 weeks. Yield losses occurred when conditions were not favorable for late season recovery of the cotton in Arizona. Blank squares resulted when *L. hesperus* fed on meristematic tissue of presquaring cotton. This was also true for *L. lineolaris* (Scales and Furr, 1968; Tugwell et al., 1976; Hanney et al., 1977).

Both yield potential of cotton and time of infestation by *L. lineolaris* were shown by Tugwell et al. (1976) to determine the type and severity of damage. Plants with extremely low yield potential sustained large numbers of *L. lineolaris* without loss in yield. Infestations at or just before onset of squaring caused significant terminal abortion, and yield was reduced 40 percent. These studies used larger bug populations than normal. The infestation period resulting in the greatest yield loss was the 3 weeks following the fourth week of squaring, when pinhead squares, small squares, and bolls were subject to injury. Nerech (1976) found the economic injury level to be a single third-instar nymph per foot of row (13,560 per acre) during the first 3 weeks of squaring, with greatest damage the first week. Abortion of terminals caused by feeding occurred at this time. *Lygus lineolaris* removed more than three squares per insect per day, with results agreeing closely with those of Mauney and Henneberry (1979) in studies with *L. hesperus*. Neresh (1976), Pack and Tugwell (1976), and Mauney and Henneberry (1979) indicated that *Lygus* spp. preferred to feed on young squares; this meristematic feeding resulted in abnormal growth, blank squares, and reduced yield. Yield reductions were greatest when plants were infested at first squaring (Scales and Furr, 1968; Neresh, 1976). Maximum damage occurred when dispersion of insects coincided with susceptible plant stages.

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ROLE OF HOST PLANTS

The wild host plants of Lygus spp. on which they feed and reproduce, and the key hosts that furnish individuals that disperse to cotton, have only recently been investigated. The relative importance of these wild host plants is determined by their abundance, effects on populations and reproductive potential of Lygus, and effects on predators and parasites of Lygus spp. Cleveland (1982) and Anderson and Schuster (1983) found a succession of weed hosts from early spring until frost for L. lineolaris. The hosts that furnished individuals dispersing to cotton when it was most susceptible to damage did not necessarily support the greatest Lygus populations. There appeared to be ecologically equivalent weed species in Texas and Mississippi.

In the Western United States, a complex of Lygus spp. is closely associated with safflower or alfalfa production (Stern, 1976; Graham et al., 1982), with L. hesperus the predominant species. Maturation of safflower or harvest of alfalfa causes dispersal of bugs to cotton, a less preferred host.

NEED FOR BIOLOGICAL CONTROL

Additional biological control is clearly needed for Lygus spp. that invade cotton. The literature indicates a succession of hosts is necessary for Lygus to increase sufficiently to damage cotton when insects disperse from plants lost through maturity or harvesting. A biological control organism effective in noncrop host plants could reduce dispersing populations to below economic levels. A noncrop host plant could also be a source of parasites for dispersion with Lygus spp. into cotton.

NATIVE PARASITES AND PREDATORS

Native parasites and predators of Lygus spp. in cotton-growing regions of the United States are shown in tables 1 and 2. Predators of Lygus spp. have not been extensively evaluated (Clancy and Pierce, 1966; Perkins and Watson, 1972; Hormchan, 1977), but the literature contains numerous references to casual observations of predation by both insects and spiders. Quantitative work is lacking, but Lygus spp. appear to have an important role in the food chain of cotton ecosystems; the genus is a facultative predator as well as a phytophagous pest.

Parasites are more specific to nymphs of plant bugs. Leiophron uniformis (Gahan) in the Western and Peristenus pallipes (Curtis) in the Eastern United States give varying degrees of nymph control at less than economic reductions. In addition, the egg parasite Anaphes ovijentatus (Crosby and Leonard) occurs across the Cotton Belt. In Mississippi, the tachinid Alophorella spp., prob. aeneoventris (Williston), and mermithid nematodes also exert a low degree of control.

Parasitization of Lygus hesperus by Leiophron uniformis never exceeded 11 percent in California according to Clancy and Pierce (1966). In Arizona, the egg parasite A. ovijentatus parasitized 34 percent of Lygus spp. eggs in London rocket but only 9 percent in alfalfa (Graham and Jackson, 1982).

Parasitization by P. pallipes occurred at 4-24 percent during the single parasite generation in eastern Mississippi (Hormchan, 1977). Limited samples were also taken in the Mississippi River Delta, but parasite effectiveness was no better than in eastern Mississippi.

EXOTIC INTRODUCTIONS

Parasites of mirids were identified from Turkey in 1971 (Drea et al., 1973) and in Europe during 1966-71 (Bilewicz-Pawińska, 1973). In 1971-72 and 1974, specimens of Peristenus stygicus Loan from Turkey and France were shipped to the United States, and cultures were established in California. The University of California initially maintained separate colonies of Turkish and French strains but eventually combined them (Van Steenwyk and Stern, 1976). During 1972-73, over 20,000

Table 1
Native parasites of *Lygus lineolaris* (Palisot) in Southeastern United States

Parasite species	Location	Source
Braconidae		
Peristenus pallipes (Curtis)	Mississippi Delta Eastern Mississippi	Scales, 1973 Hormchan, 1977
Tachinidae		
Alophorella sp., prob. *aeneoventris* (Williston)	Mississippi Delta	Scales, 1973
Mymaridae		
Anaphes ovijentatus (Crosby and Leonard)	Mississippi Delta	Scales, 1973
Nematoda, Mermithidae	Mississippi Delta	Scales, 1973

Table 2
Native parasites and predators of western *Lygus* spp. in Western United States

Parasite species	Location	Source
Braconidae		
Leiophron uniformis (Gahan)	California	Clancy and Pierce, 1966
Mymaridae		
Anaphes ovijentatus (Crosby and Leonard)	Arizona	Graham and Jackson, 1982
Nabidae		
Nabis alternatus Parshley	Arizona	Clancy and Pierce, 1966; Perkins and Watson, 1972
Lygaeidae		
Geocoris spp.	California	Clancy and Pierce, 1966

parasites were released in the San Joaquin Valley on alfalfa (Van Steenwyk and Stern, 1977). Subsequent studies showed that the parasite was ineffective.

Initial releases of *P. stygicus* from imported material were made in the Mississippi Delta on cotton during 1974 (Coulson, pers. commun.). In 1975, a colony of *P. stygicus* was obtained from the University of California at Riverside by the Department of Entomology, Mississippi State University. The California strain was increased during 1975 for biological studies with *Lygus lineolaris* and for release during the late summer in eastern Mississippi. Some releases were also made in the Mississippi Delta near Scott. A total of 800 females were released at 4 sites. Monthly sweep net samples were taken at the four sites during 1976 and 1977; nymphs were held for parasite emergence, but no parasites were recovered.

A second strain of *P. stygicus* was maintained and increased for release in Mississippi using shipments of the parasite from the European Parasite Laboratory during 1977. Small numbers of females were released in Clay, Lee, Bolivar, and Oktibbeha Counties. Sweep net samples were taken 7 days after release, and nymphs were examined for parasites in three of the locations. An average of 13 percent of the nymphs were

parasitized, but subsequent samples indicated failure of the parasites to establish reproducing populations. Adult parasites were effective when released but did not successfully complete a generation.

A third strain of P. stygicus from Spain was introduced and increased at the Biological Control of Insects Laboratory, Tucson, Ariz. (H.M. Graham, pers. commun.). Weekly releases of 1,500 to 1,900 parasites for control of Lygus hesperus were made on alfalfa during periods of bug infestation. In addition, 152,000 parasite cocoons were distributed in alfalfa during 1983. Percent parasitism in the field was low, and most parasitized nymphs were found immediately following releases of laboratory-reared adult parasites. The results were less than satisfactory.

These four efforts to establish P. stygicus for control of Lygus spp. on cotton indicate that the parasite is poorly adapted to cotton-growing regions of the United States. The cause of this species' failure to establish has not been determined.

Two other species of Peristenus have been introduced into southeastern cotton-growing regions through the European Parasite Laboratory (Hormchan, 1977). A total of 29 females and 54 males of P. rubricollis (Thomson) collected in France were sent to the Department of Entomology, Mississippi State University, in 1977. Females oviposited in L. lineolaris nymphs in laboratory studies and a few cocoons were produced, but no adults emerged.

Specimens of French Peristenus digoneutus Loan were received at Mississippi State University during 1975-76. A total of 75 females and 91 males were utilized to begin a colony, although a laboratory F_2 generation was not obtained. Twenty-five individuals were released in each of 2 sites in Oktibbeha and Bolivar Counties in 1977. Monthly sweep net collections during 1978-79 did not recover P. digoneutus from either site. The limited releases of P. stygicus and P. digoneutus were insufficient to conclude that these two species cannot become established on Lygus in the Southern United States.

The author searched for parasites in South and East Africa during 1981-83. Peristenus nigricarpus (Szepligeti) and P. praetor (Nixon) were collected from Lygidolon laevigatum Reuter in Natal, Republic of South Africa. The mirid L. laevigatum is a serious pest of seedling black wattle, Acacia mearnsii De Wild., in Natal and southeastern Transvaal as well as in Kenya. Natural parasites include P. praetor, P. nigricarpus, Chaetostricha miridiphaga Viggiani, and Telenomus spp. The two Peristenus species parasitized 60-70 percent of mirid nymphs during the second year of wattle growth and soon reduced infestations to below economic levels (Connell, 1970). Collections made at Pietermaritzburg, Richmond, and Wartburg during the fall (May) of 1981 and summer (February) of 1982 were sent to the Stoneville, Miss., quarantine facility. An F_1 generation of both parasite species was obtained using nymphs of Lygus lineolaris as the host. An F_2 generation was obtained for P. praetor, but efforts to obtain the F_3 generation were unsuccessful.

During 1983, an exploration trip was made to Kenya near Kisumu, Nyanza Province. During October, parasites of mirids were collected in the highlands north of Lake Victoria to the Ugandan border. Parasites were found in Taylorilygus indecorus (Taylor), T. vosseleri (Poppius), and T. virens (Taylor). Only cocoons from the last two species survived shipment to quarantine at Stoneville. Parasites collected were Peristenus nigricarpus and an undescribed Leiophron. The latter oviposited readily in both Lygus lineolaris and Taylorilygus pallidulus (Blanchard) but failed to emerge from cocoons (G.L. Snodgrass, pers. commun.).

The Commonwealth Institute of Biological Control laboratory in Kenya undertook additional searches for parasites of Taylorilygus spp. in 1984 and 1985 with

the support of the ARS Biological Control of Insects Laboratory, Tucson, Ariz. No parasites were collected until the last part of 1985. At that time, a shipment of the undescribed *Leiophron* was sent to the Stoneville quarantine facility, and colonies were established in *Lygus lineolaris* and *L. hesperus*. This parasite has been tested against nymphs of the predators *Orius insidiosus* (Say) (Anthocoridae), *Geocoris punctipes* (Say) (Lygaeidae), *Nabis roseipennis* Reuter (Nabidae), and *Deraeocoris nebulosus* (Uhler) (Miridae), with no parasitization of any of the species (Snodgrass, pers. commun.).

FUTURE DIRECTION - PROBABILITY OF SUCCESS

Parasites from the Ethiopian and Palaearctic regions utilized thus far for biological control of *Lygus* have not adapted to cotton-growing regions in the Nearctic region. However, a large number of species from the Ethiopian region have yet to be evaluated (Nixon, 1946). The successful culturing of the undescribed *Leiophron* from Kenya in *Lygus lineolaris* and *L. hesperus* suggests some promise. The diversity of mirid parasites in the Ethiopian region indicates that additional research on the East and West African fauna might yet yield other promising parasite species.

It is not known whether it will be feasible to use parasites for biological control of plant bugs in native host plants or in crops that sustain little damage in order to prevent large numbers of emigrants into very sensitive crops such as cotton in the United States. However, Taylor (1945) found similar ecosystem interactions in Uganda with respect to cotton. In Uganda, the brown lygus bug, *Taylorilygus vosseleri*, is a pest of cotton that moves into cotton from maturing wild host plants found in the elephant grass zone. Parasitization of *T. vosseleri* by *Peristenus* on these wild hosts is continuous, and when it disperses to cotton, the parasites disperse with it. Biological control was rather effective in the small cotton fields characteristic of that area. Case histories from Europe and Africa indicate that successful biological control of *Lygus* spp. could be possible with successfully adapted parasites.

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BIOLOGICAL CONTROL EFFORTS AGAINST *LYGUS* AND *ADELPHOCORIS* SPP. INFESTING ALFALFA IN THE UNITED STATES, WITH NOTES ON OTHER ASSOCIATED MIRID SPECIES

By W.H. Day[1]

Alfalfa is an important crop in the United States. Nearly 27 million acres are grown each year, an area exceeded only by wheat, corn, and soybeans (Johnson, 1982). It is the principal protein source for dairy and beef cattle and for most other farm animals.

Many insect species feed on alfalfa. However, only a few (number varies among locations and years) significantly affect the costs of producing alfalfa by reducing stand or yield or by requiring chemical or other control measures. Because alfalfa is not native to the Western Hemisphere, it is not surprising that most of its major insect pests have been accidentally introduced into North America, and for this reason many of these pests have been the target of applied biological control research by the U.S. Department of Agriculture. As a result of these parasite introductions, the alfalfa weevil, Hypera postica (Gyllenhal), once the most important insect pest of alfalfa nationwide, now is at such low levels that it causes little or no damage in most of the eastern third of the United States north of latitude 36° N. (Day, 1981). Similar results have been obtained against two other introduced pests, the pea aphid, Acyrthosiphon pisum (Harris) (Angalet and Fuester, 1977) and the alfalfa blotch leafminer, Agromyza frontella (Rondani) (Hendrickson and Plummer, 1983).

As a consequence of these successful research projects in the Northeastern States, only a small proportion of established alfalfa stands is now treated with insecticides, with a savings to agriculture of millions of dollars each year (Day, 1981). Most of the insecticides still applied to alfalfa in this region are used against the potato leafhopper, Empoasca fabae (Harris). Since economic populations of this insect are produced by migrants arriving from the Gulf States in late spring, injurious populations usually do not develop until midsummer to late summer. Damage to alfalfa is most severe if young, spring-seeded fields are heavily infested. Occasionally moderate injury occurs in older, established fields, especially during summers with inadequate rainfall. Overall, however, I estimate that only about 5-20 percent of alfalfa fields, depending on the State, are treated for leafhopper control. The absence of severe damage to most alfalfa acreage has directed attention to other insects that feed on alfalfa in the Northeast, like the plant bugs (Miridae: Adelphocoris, Lygus, and others). Research on this plant bug complex is warranted because--

(1) Several species of mirids feed on alfalfa, and others attack timothy and other grasses that are planted with alfalfa.

(2) Damage by these sucking insects is much less obvious than injury by chewing insects, so either it is unnoticed or it is confused with damage caused by nutrient deficiencies, leafhoppers, aphids, or plant diseases (Day, unpub.; Osborn, 1939; Radcliffe and Barnes, 1970).

(3) The plant bugs apparently have become more abundant because of greatly reduced insecticide use or reduced competition by the alfalfa weevil.

(4) Alfalfa, being a perennial, serves as a reservoir for the tarnished plant bug, Lygus lineolaris (Palisot), and the legume bug, L. hesperus Knight, which have been serious pests of numerous fruit and vegetable crops for many years (Crosby and Leonard, 1914).

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Chemical control of the alfalfa-infesting plant bugs is no longer a desirable solution in the Northeastern United States, because parasite mortality and, consequently, reduced biological control of these three pests would result. For this reason in the early 1970's, entomologists at the ARS Beneficial Insects Research Laboratory at Newark, Del., became interested in the possibility of reducing plant bug numbers in alfalfa with introduced parasites. This work dovetailed with exploration studies that had been underway for several years at the ARS European Parasite Laboratory in France (an extension of the pioneering work by Bilewicz-Pawiński in Poland, sponsored by the USDA PL-480 program) and related research in the Southwestern States. In the Southwest, Federal and State entomologists were interested in the biological control of Lygus spp. in forage alfalfa, primarily to reduce the number of plant bugs emigrating to cotton, and in alfalfa grown for seed.

This report is an attempt to integrate and summarize the large amount of available information from the literature and my ongoing research on the mirids that are important pests of alfalfa and alfalfa-grass crops. Additional information may be found in other reports in this publication.

THE MIRID COMPLEX IN ALFALFA

Species and Host Plants

The common plant bugs found in alfalfa and alfalfa-grass mixtures in North America are listed in table 1. Keys and drawings of these species to aid in their identification are in Knight (1941) and Slater and Baranowski (1978). Two ecological homologs, *Lygus pratensis* (L.) and *L. rugulipennis* Poppius, which occur in Europe, have been included in table 1 for comparison. Mirid species that feed primarily on weeds present in most older alfalfa fields are not listed.

The alfalfa plant bug, *Adelphocoris lineolatus*, is a comparatively recent introduction from Europe (Knight, 1922). It is generally regarded as a significant pest only of alfalfa that is used for seed and forage production (Craig, 1963; Newton and Hill, 1970). The related rapid plant bug, *A. rapidus*, is also included in table 1 because occasionally it is abundant and has been regarded as a pest of alfalfa. However, it probably feeds mainly on *Rumex* weeds in alfalfa fields (Slater and Baranowski, 1978).

The meadow plant bug, *Leptopterna dolabrata*, an early immigrant from Europe (Osborn, 1918), is usually the most numerous mirid in the spring in northeastern alfalfa fields that have been planted in a mixture of alfalfa and timothy or other grasses (Day, unpub.). I am not aware of an economic impact study of this insect on forage grasses, but its sheer numbers suggest that it has a deleterious effect on at least the grass component of the yield (Day, unpub.; Osborn, 1918).

Two native species of *Lygus* (*hesperus* and *lineolaris*) are important pests of alfalfa in North America (table 1). Their coloration varies with age (Day, unpub.), temperature (Kelton, 1975) (darker shades occurring in cooler locations and seasons), and possibly also among different host plants. These color differences have caused considerable confusion as to the identity and the number of species actually present (Kelton, 1975).

Lygus bugs are not without some beneficial habits. Apparently all *Lygus* spp. are able to feed on other insects, especially when short of food (Kelton, 1975; Wheeler, 1976), and for optimum development this predation may even be required (Bryan et al., 1976). However, since in most field situations the mirids greatly outnumber aphids and other potential prey, their phytophagous activities are likely to be much more important than their predatory tendencies. Other evidence indicates that aphid honeydew may be essential for survival if alfalfa is not yet in bloom or does not contain flowering weeds (Butler, 1968). Because *Lygus* spp. feed on weed flowers and seeds, some reduction

Table 1
Common mirid species found in alfalfa and alfalfa-timothy fields in North America[1]

Species	Generations/ year	Over-winter	Distribution[2]	Hosts	Origin[3]
1. *Adelphocoris lineolatus* (Goeze) alfalfa plant bug	2-3	Egg	N, Eur	Alfalfa, sweetclover, vegetables, fruits; buds, seeds	Introduced
2. *A. rapidus* (Say) rapid plant bug	1-2	Egg	NE	Dock, clovers, cotton	Native
3. *Leptopterna dolabrata* (L.) meadow plant bug	1	Egg	N, Eur	Timothy, orchardgrass	Introduced
4. *Lygus hesperus* Knight legume bug	2-5	Adult	W	Alfalfa, cotton, insects, weeds, beans; western 1/3 U.S.	Native
5. *L. lineolaris* (Palisot) tarnished plant bug	2-4	Adult	NA	Legumes, insects, vegetables, fruits, weeds (*Erigeron*, milkweed, etc.)	Native
6. *L. pratensis* (L.) (resembles *L. rugulipennis* Poppius and confused in literature until 1951)	2-3	Adult	Eur	Similar to L. *rugulipennis* as far as is known	---
7. *L. rugulipennis* Poppius European tarnished plant bug	2-3	Adult	Eur	Alfalfa, potato, rye, weeds, flowers	---
8. *Megaloceroea recticornis* (Geoffroy)	1	Egg	NE, Eur	Bluegrass, fescues, other grasses	Introduced
9. *Stenotus binotatus* (F.) timothy grass bug	1	Egg	N, Eur	Orchardgrass, timothy	Introduced
10. *Trigonotylus coelestialium* (Kirkaldy) green grass bug	1-2	Egg	N	Timothy, oats, grasses	Native

[1]Data from Bilewicz-Pawińska (1970), Crosby and Leonard (1914), W.H. Day (unpub.), Graham (1982), Hardee et al. (1963), T.J. Henry (pers. commun.), Kelton (1975), Knight (1922, 1923), J.D. Lattin (pers. commun.), Osborn (1918), Slater and Baranowski (1978), Southwood (1956), Stephens (1982), Watson (1928), and Wheeler (1974).

[2]Eur = Europe; N = northern 1/2 of North America; NA = North America; NE = northeastern 1/4 of NA; W = western NA.

[3]Introduced = introduced into North America; native = native to NA; --- = not present.

of weeds likely occurs, as suggested by Snodgrass et al. (1984). However, any benefit would be offset if the increased plant bug numbers resulting later moved into nearby crops. Finally, Scott (1983) has found that lygus bugs may increase yields of certain crops by pollinating flowers and, surprisingly, also by a delayed stimulation effect on the seed that they have consumed.

In the Western States, L. hesperus is much more numerous on alfalfa than L. lineolaris (table 1). The former species could be called the western tarnished plant bug, because it occupies approximately the same ecological niche as L. lineolaris does in the East, attacking cotton and many other crops in addition to alfalfa. A closely related species, L. elisus Van Duzee, is seldom abundant in southwestern alfalfa (Graham et al., 1982, 1986). What was long thought to be a third species on alfalfa, L. desertinus Knight, will probably be eventually declared a synonym or subspecies of L. elisus, because two-way crosses yielded progeny readily in laboratory tests, and the offspring of single females from the field included individuals of both "species" (Sluss et al., 1982; Graham, 1982). The western Lygus complex is especially important, because most of our alfalfa seed is produced there, and large reductions in seed yield (Carlson, 1946) are more likely to result from mirid feeding than are reduced foliage yields. However, forage yield losses have also been documented (Stitt, 1948; Newton and Hill, 1970). In addition, forage alfalfa is often an important reservoir for L. hesperus, which emigrates to cotton and other nearby crops when the alfalfa is mowed.

Lygus lineolaris is often very numerous in alfalfa fields in the Eastern and Central States. As previously mentioned, it feeds on a wide range of crops (Scott, see p. 40) and weeds (Snodgrass et al., 1984) (table 1). Many overwinter in alfalfa, because it offers considerable cover since it is not plowed or cultivated annually like most crops, and, in addition, large numbers are produced in alfalfa during the summer (Day, unpub.). Significant damage to alfalfa has been documented by Newton and Hill (1970). The movement of both adults and nymphs (Kelton, 1975; Khattat and Stewart, 1980) from one plant host to another suggests that alfalfa serves as an important source of L. lineolaris infestations in fruit and vegetable crops. Consequently, reduction of this insect by parasites, even if the latter are restricted to alfalfa, could be of broad economic importance.

In Europe, there are apparently also two similar Lygus species (table 1), which were confused until comparatively recently (Southwood, 1956), that have broad host ranges. The "European tarnished plant bug," L. rugulipennis (Southwood, 1956) is by far the most important species.

The remaining species in table 1 feed only on grasses in alfalfa fields as far as is known. Megaloceroea recticornis has been reported as a pest of lawn and pasture grasses (Kamm, 1979) and other grasses (Slater, 1956) in the United States, but I have not discovered any reference indicating that this introduced species reduces yields of the timothy or orchardgrass frequently planted with alfalfa. It is listed in table 1 because it is often common in mirid samples from northeastern alfalfa fields.

The timothy grass bug, Stenotus binotatus, is another grass-feeding, introduced plant bug (table 1). In my field observations, it has been second or third in abundance in alfalfa-grass mixtures, and it is also abundant in New York (Hardee et al., 1963), so it may well have an economic impact. This species feeds on timothy and orchardgrass (Watson, 1928), both commonly planted with alfalfa (Knapp and Seaney, 1979). Since the nymphs closely resemble Adelphocoris lineolatus nymphs, especially the early instars, skilled identification is necessary to make accurate field counts of these two species. Adults are easily identified.

The green grass bug, Trigonotylus coelestialium, is a small, slender mirid that is usually less numerous than the

other grass-feeding species (table 1). It is probably of little economic importance in alfalfa-grass plantings.

Biology of Common Mirids

Table 1 also includes additional biological information that can be useful in devising sampling or control methods. Obviously, species with more than one generation each year will generally be more difficult to control by biological or other means, because an additional generation allows the population to compensate by reproduction or emigration in the same year for earlier mortality.

Presumably the mirids that overwinter as adults would also have an advantage, because the mobile adults can relocate in the spring, colonizing fields with low or zero infestations. However, of the listed species, only members of the genus *Lygus* overwinter in the adult stage.

An approximate time of occurrence and sequence of the common mirid nymphs in the Northeastern States is in figure 1. Adult mirids have not been included, because they are generally long lived (the resulting overlap prevents separation of generations) and because only the nymphs are parasitized

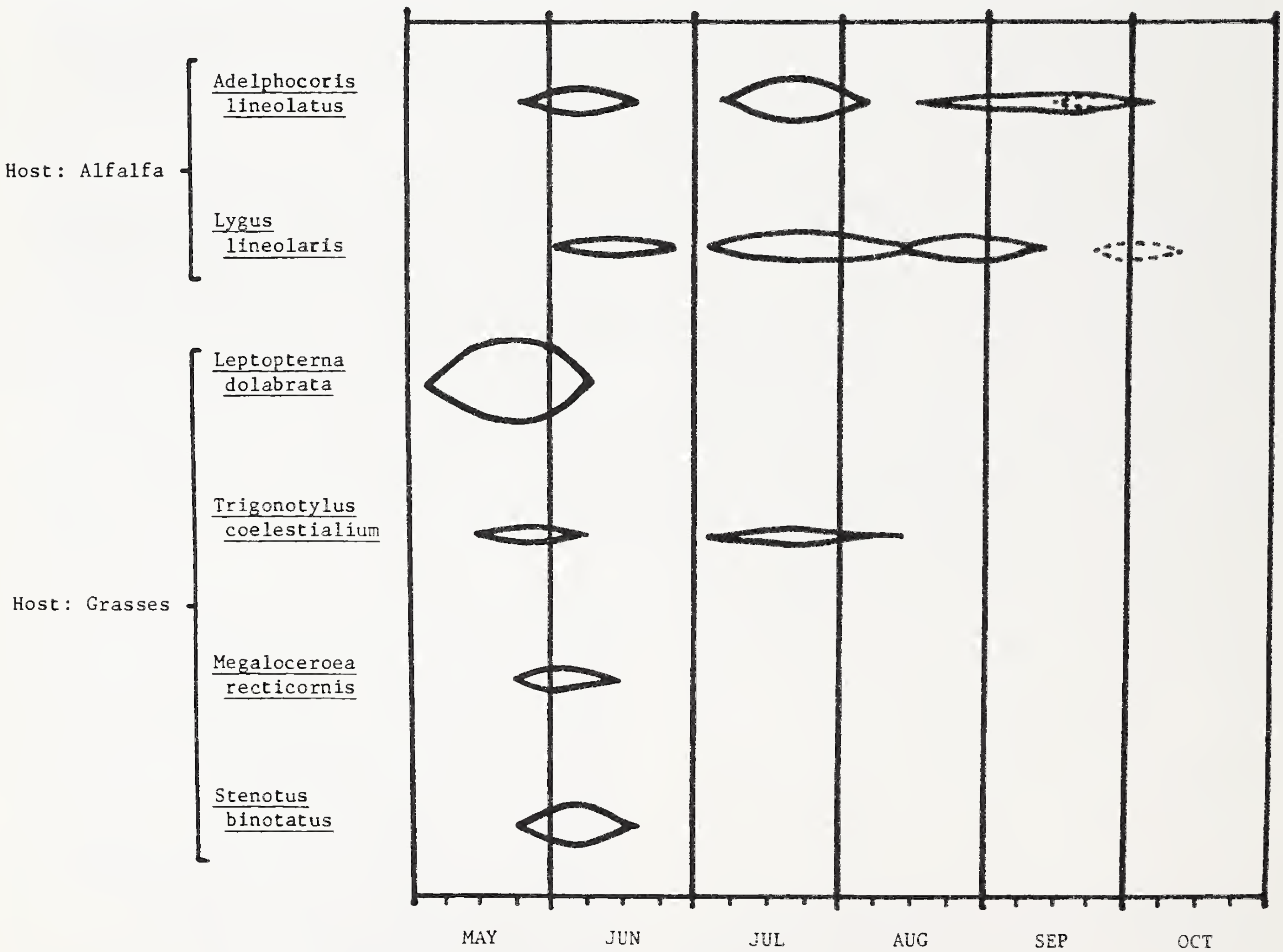

Figure 1
Approximate time of occurrence, relative abundance (ellipse height), and number of generations of common mirid nymphs in northeastern alfalfa-grass fields, 1978-82. Dotted lines indicate occasional fourth generations of *A. lineolatus* and *L. lineolaris*.

significantly. The "height" of each ellipse represents the relative abundance of each species and generation. Since most of these mirid species feed on grasses, they will be scarce or absent in young, pure plantings of alfalfa, which contain few weed grasses. In such situations, Adelphocoris and Lygus are usually the only genera abundant enough to be of possible economic importance. In irrigated fields in the Southwest, only Lygus is regarded as a significant pest. Whether or not grasses are present with the alfalfa, it is important to note that there is a complex of species, generations (fig. 1), and stages of the mirids that combine to provide continuous feeding "pressure" on the crop throughout the growing season. This probably increases the importance of what might otherwise be minor feeding damage.

PARASITES AND PREDATORS

Parasitism by Native Species

Once the species of the target pest have been identified and their relative importance is estimated, it is necessary to determine the species of parasites that are already present. Very little was known in North America prior to the comparatively recent work by Loan (1965) and Clancy and Pierce (1966). However, since then considerably more information has been obtained, and this has been summarized in table 2. Several points that are not self-explanatory are discussed here.

No species of nematodes are listed by Poinar (1975) as parasites of the American species of mirids listed in table 1--a reflection of the difficulty in rearing nematodes to the adult stage as required for identification, their low incidence, and the small number of intensive investigations on parasites of mirids. Welch (1965) has stated that low levels of nematode parasitism are likely, except in wet or very humid environments, and my observations agree (table 3).

Little work has been done on secondary parasites. All common species are in the genus Mesochorus and are solitary endoparasites of braconid larvae. The Mesochorus egg is injected into the braconid when it is inside the live mirid host. Braconid cocoons are believed to largely escape additional hyperparasitism because they are concealed and dispersed in the soil, but I am not aware of this actually having been investigated. The data, along with data of Lim and Stewart (1976) and Dasch (1971), are not sufficient to indicate whether all Mesochorus spp. in North America are the same species as in Europe, but R.W. Carlson (pers. commun.) has recently determined that my specimens are all morphologically identical to the European M. curvulus Thomson.

Measurement of the effectiveness of the native primary parasites is difficult. A two-step process is necessary: The parasites must be identified and the amount of parasitism must be accurately measured. For identification of the parasites of nymphs and adults, the hosts must be collected, identified, separated by species and stage, and fed adequately until the parasites exit; suitable pupation media must be provided for the braconids; and diapausing parasites in cocoons must be kept alive for many months until the adult parasites emerge, as adults are required for identification. In most instances, since this long rearing process results in substantial mortality of both hosts and parasites, accurate data on the degree of parasitism are not obtained by this method. Clancy and Pierce (1966) pointed this out and indicated that dissection was the only accurate method for measuring parasitism. My data (Day, unpub.) for 1982 corroborate this. Parasitism by dissection was 48 percent higher than by rearing, showing that the rearing method seriously underestimates parasitism, probably because the survival of parasitized mirids is markedly lower than unparasitized individuals. Samples too large to dissect in 1 day can be frozen at -15°C (Day, 1971), so the work can be done over an extended period.

Most of the data available, including references cited here and my data referred to later, indicate that

Table 2
Common parasites in North America of mirids associated with alfalfa[1]

Parasites	Family[2]	Hosts	Generations/yr[3]	Plant association
Anaphes ovijentatus (Crosby and Leonard)	My	*Lygus lineolaris*, *L. hesperus*	2-4	Alfalfa, weeds
Leiophron uniformis (Gahan)	Br	*L. hesperus*, *L. elisus*, *L. lineolaris*	2-4	Alfalfa, weeds
L. trigonotylidis (Loan)	Br	*Trigonotylus coelestialium*	(?)	Grasses
Peristenus pallipes (Curtis)[4]	Br	*L. lineolaris*, *Adelphocoris lineolatus*, *Leptopterna dolabrata*	1-E	Alfalfa, weeds, grasses
P. pseudopallipes (Loan)	Br	*L. lineolaris*	1-L	*Erigeron* (not alfalfa)
Alophorella aeneoventris (Williston) (plus occasionally *A. fumosa* and possibly *A. pulverea* and *A. opaca*)	Ta	*L. lineolaris*, *L. elisus*, *L. hesperus*, *L. dolabrata*, *Stenotus binotatus*, Pentatomidae, Cercopidae	(?)	Alfalfa, weeds
Undetermined nematode	Me	*A. lineolatus*, *L. lineolaris*, *S. binotatus*	(?)	Alfalfa, grasses
Mesochorus curvulus Thomson[5] (also *M. acuminatus* (Thomson) and *M. punctifrons* Dasch)	Ic	*Leiophron*, *Peristenus*	2-3	Alfalfa, grasses, weeds

[1]Data from Loan (1970, 1980), Shahjahan and Streams (1973), and Day (unpub.) except as indicated in footnotes.

[2]Br = Braconidae; some generic and specific names are different in references published prior to revisions by Loan (1974a). Ic = Ichneumonidae; secondary parasites; for further information, see Dasch (1971). Me = Mermithidae; possibly *Hexamermis*; must be reared to adult stage for identification (Poinar, 1975). My = Mymaridae (Crosby and Leonard, 1914; Clancy and Pierce, 1966; Jackson and Graham, 1983). Ta = Tachinidae (Arnaud, 1978); some of these species may be synonyms and some host records may be erroneous.

[3]Number of generations of polyvoltine species varies with length of growing season. E = spring-early summer; L = late summer-fall.

[4]This species is rare in Southwestern United States (Clancy and Pierce, 1966).

[5]The *Mesochorus* species that emerge from mirids are secondary parasites and attack the braconid primary parasites.

Table 3
Parasitism of mirids in New Jersey alfalfa, by dissection

Hosts	Number sampled	Parasitism[1] of nymphs (%)					Number sampled	Parasitism[1] of adults (%)				
		Brac.	Tach.	Nema.	Fung.	Total		Brac.	Tach.	Nema.	Fung.	Total
Adelphocoris lineolatus[2]	339	11.2	0	0	0.3	11.5	418	0	0	0.2	1.7	1.9
Leptopterna dolabrata[2]	[3]203	36.9	0	0	0	36.9	[3]162	2.5	0	0	0	2.5
Lygus lineolaris	357	10.1	0	1.4	0	11.5	626	4.5	.8	.8	0	6.1
Megaloceroea recticornis[2]	[3]103	6.8	0	0	1.0	7.8	[3]86	0	0	0	0	0
Stenotus binotatus[2]	[3]73	0	0	1.4	0	1.4	[3]114	0	0	0	0	0
Trigonotylus coelestialium	[3]25	[4]32.0	0	0	0	[4]32.0	111	2.7	0	0	0	2.7
% mortality	---	95	0	3	1	100	---	66	9	11	13	100

[1]Brac. = Braconidae; Tach. = Tachinidae; Nema. = nematode; Fung. = fungus disease.

[2]Accidentally introduced into North America.

[3]Most of these samples were from Warren County, N.J. (1982-83). All other samples were from this location and Burlington County, N.J., in 1983. Mirids were collected by sweeping 3 fields per county at weekly (May-June) and biweekly (July-Oct.) intervals.

[4]Unreliable data due to small sample size.

parasitism of the nymphal stage of most common alfalfa-grass mirids in the United States is 0 to 20 percent. This is not surprising, because four (57 percent) of the seven common U.S. mirids (table 1, species 1, 3-5, 8-10) affecting alfalfa and associated grasses are known to be introduced species, and they usually establish with few or none of their natural enemies. In addition, alfalfa is not native to North America, which may explain why native parasites of Lygus lineolaris attack this pest in certain weeds but not in alfalfa, as reported by Shahjahan and Streams (1973).

An example of the type of data needed to evaluate parasitism is in table 3. All generations of the multivoltine species have been combined in this table to allow space for both stages and the minor mortality factors. These data show that overall only one species, Leptopterna dolabrata, is parasitized to even a moderate degree. This also suggests that Peristenus pallipes may have also been introduced along with L. dolabrata rather than be a Holarctic species, because (1) this parasite is apparently also present in Europe (Loan, 1974b), and (2) although the major parasite of the native Lygus lineolaris in the United States is also P. pallipes, the degree of parasitism is much less, which suggests a recent host-parasite association.

For all species except L. lineolaris (table 3), it is also noteworthy that the adult stage is much less affected by natural enemies. In most instances, these are parasites that failed to complete their development and kill the host prior to the final nymphal molt. Lygus lineolaris also was the principal mirid parasitized by tachinids (Alophorella spp.), which apparently oviposit only in adults; none have been found in the large numbers of nymphs that have been dissected (Day and Saunders, unpub.). These two exceptions may be due

to long coevolution, because L. lineolaris is a native species, whereas all but one of the other species are immigrants.

Only a small proportion of any mirid stage and species was parasitized by nematodes, fungi, and tachinid flies (table 3). The braconids were of much greater importance, affecting 95 percent of all parasitized nymphs and 66 percent of the parasitized adults (table 3).

The need for additional parasite species is also obvious in table 4. Parasitism of the second and third generations of the alfalfa-feeding mirids (A. lineolatus and L. lineolaris) is especially low and would require establishment of a bivoltine parasite like Peristenus digoneutis Loan or a polyvoltine species like Peristenus stygicus Loan. Parasitism of the introduced grass-feeding mirids M. recticornis and S. binotatus is also insignificant. As noted earlier, S. binotatus is very abundant and may thus warrant a search for parasites in Europe.

Generally less attention has been given to parasites of the egg stage. Probably this is because mirid eggs are very difficult to sample in adequate numbers since they are small and embedded in plant stems. Graham et al. (1986) in Arizona have found parasitism of Lygus eggs up to 75 percent, but usually the high percentages occurred only in low mirid populations, when mowing of the alfalfa had been delayed 2-4 weeks, or in certain weeds. Evidently only one species, Anaphes ovijentatus (Crosby and Leonard), commonly attacks mirid eggs, and it parasitizes a variety of host species (Jackson and Graham, 1983). Clancy and Pierce (1966) found nearly 50 percent of second- and third-generation Lygus eggs to be parasitized, and Sillings and Broersma (1974) found 64 to 85 percent of the same generations to have been attacked. I have not seen egg parasitism data in the literature for genera other than Lygus.

Considerably more information has been published on parasitism of mirid nymphs. However, the picture is still

Table 4
Parasitism[1/] of mirid nymphs in New Jersey alfalfa, by generation

Hosts	Generation 1		Generation 2		Generation 3	
	Number sampled	Parasitism (%)	Number sampled	Parasitism (%)	Number sampled	Parasitism (%)
Adelphocoris lineolatus[2/]	171	20	91	0	77	4
Leptopterna dolabrata[2/]	202	37	([3/])	---	([3/])	---
Lygus lineolaris	81	27	116	6	160	4
Megaloceroea recticornis[2/]	103	7	([3/])	---	([3/])	---
Stenotus binotatus[2/]	73	0	([3/])	---	([3/])	---
Trigonotylus coelestialium	21	[4/]38	2	[4/]0	([3/])	---

[1/]By dissection. Sampling methods same as in table 3. Only major parasites (Braconidae) included in this table.

[2/]Accidentally introduced into North America.

[3/]No generation.

[4/]Unreliable data due to small sample size.

incomplete. Some reports cover only part of the generations or species of the mirid complex, whereas others have used rearing, which considerably underestimates the degree of parasitism, rather than the dissection method.

For Adelphocoris lineolatus, Loan (1965) observed 40-60 percent parasitism of the first generation in Ontario, considerably higher than I have observed in New Jersey (table 4). Wheeler (1972) noted 0-5 percent mortality by a fungus disease in a 4-year study in New York. Additional information for Canada is in Craig and Loan (see p. 48).

Parasitism levels of Lygus lineolaris that are similar to our results have been reported by Loan (1965), with rates of 30 percent in the first generation and 12 percent in the second generation in Ontario. Lim and Stewart (1976) found only 5 percent parasitism in the first generation in alfalfa, but 8 percent in the second generation in weeds. Shahjahan and Streams (1973) reported average parasitism rates of 20-30 percent (apparently first and second generations, but not stated) on weed hosts, although the rates varied considerably among the species of weeds.

Only low nymphal parasitism rates for Lygus hesperus, the western homolog of L. lineolaris, have been recorded. Clancy and Pierce (1966) reported about 1 percent parasitization of the first several generations, and 5-7 percent for the last two to three generations during 2 years. Graham et al. (1986) observed a 1-5 percent parasitization of the third and fourth generations on forage alfalfa in Arizona; higher rates were occasionally observed where mowing had been delayed and in fields grown for seed.

Parasitism data in the literature on the remaining mirid species are limited. The only reference to Leptopterna dolabrata that I have found (Loan, 1980) listed a 42 percent parasitization in Ontario collections, slightly higher than my results in New Jersey (table 4).

No literature data have been found for Megaloceroea recticornis to compare with the low rates in New Jersey (table 4).

Stenotus binotatus, which is evidently regarded as a pest of timothy in Europe (Watson, 1928), has not yet been recognized as an important pest in North America. Thus, no parasitism data have been previously published to my knowledge for comparison with the zero rates I have observed (table 4).

Parasitism of the native Trigonotylus coelestialium, one of the green grass bugs, was surprisingly high (table 4) in its first generation and then insignificant in the second generation in New Jersey. Loan (1980) reported a slightly higher (43 percent) rate for the first generation in Ontario.

Predation by Native Species

Several species of Nabis (Nabidae) (Perkins and Watson, 1972; Wheeler, 1977), Chrysopa (Chrysopidae) (Wheeler, 1977), and spiders (Oxyopidae, Tetragnathidae, Thomisidae) (Wheeler, 1971) have been observed feeding on Lygus and Adelphocoris in alfalfa fields.

Although several species of Geocoris (Lygaeidae) are regarded as important predators of Lygus in California cotton (Leigh and Gonzalez, 1976), other investigators in Arizona concluded that they were not effective in reducing mirid populations (Wene and Sheets, 1962). Crocker and Whitcomb (1980) did not observe Geocoris feeding on mirids in alfalfa, although they did record this predator eating mirids on other host plants. They also observed Geocoris feeding on dead insects, beneficial species, and plants, and they noted that this omnivorousness will confound estimates of control value. Gupta et al. (1980) studied prey consumption by Geocoris bullatus (Say) in the laboratory, observing that Acyrthosiphon pisum was preferred over mirids and that late-instar Lygus nymphs and adults were too large to be captured. Nevertheless,

they concluded that Geocoris is the major natural enemy of Lygus in Washington State alfalfa.

Wheeler (1977) found several additional predator taxa in alfalfa (Orius, Podisus, coccinellids, sphecids, and vespids) but did not observe them attacking Lygus or Adelphocoris. However, sphecids were reported by Kurczewski and Peckam (1970) to provision their nests with Lygus in New York State.

At present, the effectiveness of predators in preventing outbreaks or reducing damaging populations of alfalfa-feeding mirids in the field remains largely unknown. This is primarily because predation is much more difficult to quantify than parasitism in nature. The percentage of the mirid population that has been parasitized at any one time is relatively easily and accurately determined, as outlined earlier. On the other hand, the direct measurement of predation in the field is prevented for the following reasons: Mirids that have previously been consumed by predators usually cannot be counted; each predator feeds on many prey in its lifetime; the prey consumption rate varies considerably among the numerous stages and instars of both the predator and the prey; and the wide range of species accepted as prey by most predators leaves much uncertainty regarding the number of mirids that have been consumed. Extrapolation of laboratory feeding tests to field conditions adds further biases, and large errors are likely (Crocker and Whitcomb, 1980).

Parasite Species in Europe

As mentioned earlier, the ARS European Parasite Laboratory in France has been exploring for exotic parasites of mirids for several years. Prior to this, ARS had a cooperative agreement with Teresa Bilewicz-Pawińska in Poland. I have summarized pertinent results of the collections and rearings in Europe by these two groups in table 5. Further details are in Hedlund (see p. 76).

It is important to note that since collection efforts have been mostly concentrated on Lygus rugulipennis, the ecological equivalent of our L. lineolaris and L. hesperus, larger numbers of parasites have been obtained from this host. Fewer Adelphocoris lineolatus specimens have been collected because this species was not a target pest in the early years, and later because even moderate field populations of this species are rare under the short European harvesting schedules (Hedlund, pers. commun.). Collections in Europe were concentrated on alfalfa to avoid parasite species or subspecies that were not adapted to this crop.

As in the United States, the dominant parasites were all braconids. Moreover, because three of the four braconid species attacked both Lygus and Adelphocoris (table 5), they were potentially more useful parasites. In most samples, parasitism rates were considerably higher than in the United States (K. Carl, J.J. Drea, R.W. Fuester, R.C. Hedlund, pers. commun.). This is an important additional indicator of their biological control potential.

Tachinids and nematodes were, in contrast, rarely found to be significant parasites in Europe (CIBC, 1979).

Parasite Shipments From BIRL Quarantine

Until 1982, all imported parasites of mirids were processed through quarantine at the ARS Beneficial Insects Research Laboratory (BIRL) at Newark, Del. The primary parasites that emerged were then sent to various State and Federal cooperators. Table 6 gives the number of parasites released in the field in each State or Province and the percentage released (number released divided by number received).

At several locations, one species of parasite, Peristenus stygicus, was successfully reared in the laboratory, so more were released than had been received. This may increase the odds for

establishment, especially if the individuals released are F_1 or F_2, so they have not undergone prolonged selection to artificial conditions in the laboratory.

In other instances, field releases were few or nonexistent because laboratory culture was attempted with all or most of the parasites received, and the species could not be successfully reared. Peristenus digoneutis and, especially, P. rubricollis have a diapause that has impeded their rearing. Similar difficulties are likely with P. adelphocoridis. Diapause and the small numbers received so far have not made laboratory rearing a practical alternative. In a few other instances, only laboratory studies were planned at the outset.

The principal target pests for the parasites listed in table 6 have been Adelphocoris lineolatus and Lygus lineolaris in the Northeast, L. lineolaris in the South Central, and L. hesperus in the Southwest.

Locations where significant numbers of parasites have been released have been systematically checked for parasite establishment. Places with positive recoveries are listed in table 7. Although a few locations have produced parasites, the results have not been encouraging. Parasite release and recovery efforts are continuing only in Warren County, N.J., and in Pima and Cochise Counties, Ariz., where it is hoped that successful establishment will result in the next several years.

Table 5
Common parasites in Europe of mirids associated with alfalfa

Parasites[1/]	Family[2/]	Hosts[3/]	Generations/ yr[4/]	Plant association
Peristenus adelphocoridis Loan	Br	Adelphocoris lineolatus (F)	1-E	Alfalfa
P. digoneutis Loan	Br	Lygus rugulipennis (F), A. lineolatus (F)	2-3	Alfalfa, potatoes, rye
P. rubricollis (Thomson)	Br	L. rugulipennis (F), A. lineolatus (F)	1-E	Alfalfa, rye
P. stygicus Loan	Br	L. rugulipennis (F), L. lineolaris (L), L. hesperus (L), Polymerus unifasciatus (F.) (F), A. lineolatus (L)	2-4	Alfalfa, weeds, potatoes, and other vegetables
Alophora obesa (F.)	Ta	Lygus sp. (F)	(?)	Alfalfa, clover

1/In addition, the same nominal species of Mesochorus (table 2) is known from Europe and also an unidentified mermithid nematode (Bilewicz-Pawińska and Kamionek, 1973). Data based on Bilewicz-Pawińska (1970), Drea et al. (1973), and Fuester (pers. commun.).

2/Br = Braconidae. Most generic and specific names are different in references published prior to revisions by Loan (1974b, 1979) and Loan and Bilewicz-Pawińska (1973). Ta = Tachinidae.

3/Verified by laboratory (L) or field (F) (more accurate) observations by W.H. Day, J.W. Debolt, L.R. Ertle, R.W. Fuester, and R.C. Hedlund (unpub.). L. rugulipennis may have included some L. pratensis.

4/This varies for polyvoltine species with length of growing season; E = spring-early summer.

Table 6
Disposition of European parasites of mirids shipped from ARS Beneficial Insects Research Laboratory, 1963-83[1]

Region	State or Province	Peristenus spp. released				Alophora	Agamermis decaudata[2]
		adelphocoridis	digoneutis	rubricollis	stygicus		
NE	Del.[3]	---	1,182 [5]92%	428 80%	[4]6,702 780%	15 100%	---
	Md.	---	---	---	---	---	0 0%
	N.J.[3]	48 76%	7,232 100%	155 100%	[4]2,103 74%	--- ---	--- ---
	Quebec	---	0 0%	--- ---	0 0%	--- ---	--- ---
SC	Miss.	---	173 18%	0 0%	216 23%	--- ---	--- ---
	Tex.	---	0 0%	0 0%	511 45%	--- ---	--- ---
NW	Wash.	---	---	---	0 0%	--- ---	--- ---
SW	Ariz.[6]	---	0 0%	51 15%	[4]135,884 20,800%	--- ---	--- ---
	Calif.	---	100 66%	0 0%	[4]16,263 12,050%	--- ---	--- ---
Totals:							
Shipped[7]		63	9,772	1,176	7,349	15	31
Released		48 76%	8,687 89%	634 54%	161,679 2,200%	15 100%	0 0%

[1]Based on information provided by recipients of shipments. Proportion of males in each release varied, usually between 45-55 percent.

[2]Nematode - A. decaudata Cobb, Steiner, Christie.

[3]Releases by ARS-BIRL, Newark, Del.

[4]Including a significant proportion of laboratory-reared parasites and (Arizona only) parasitized hosts (J.W. Debolt, pers. commun., 1983). Number of parasitized hosts has been discounted to allow for parasite mortality and unparasitized individuals.

[5]Proportion released (92% of 1,285 shipped in this case).

[6]In addition, there were 92 undetermined Peristenus specimens received here in 1971-72; 52 of them were released.

[7]If cocoon stage shipped (a few cases), actual number emerged was significantly less.

Table 7
Recoveries of European parasites of mirids in the United States, 1964-84

State	County	Year Collected	Year p-r[1]	Recovered parasites Species[2]	Recovered parasites Amount	Sex	Tentative establishment	Remarks
Ariz.	Pima	1982	0	Ps	Many	(?)	---	Parasites recovered same year as released only; most fields later plowed under
Calif.	Kern	1974-75	1-2	Ps	(?)	(?)	([3] [4])	Parasitism less than 1%; field converted to housing by 1979[5]
Del.	New Castle	1978	1	Pr	10	Male	---	Dissected ex cocoons
		1979	2	Pr Ps	1 1, 1	Male Male, female	([3] [4])	Male only; see 1980 remarks
		1980	3	---	0	---	---	Previous tentative establishment not confirmed
N.J.	Burlington	1972	0	Ps	2	Male	---	Parasites recovered same year as released
	Warren	1983, 1984	1	Pd	2, 1	Male, female	([3])	

[1]p-r = post release.

[2]Pd = Peristenus digoneutis, Pr = P. rubricollis, Ps = P. stygicus. All parasites were reared from hosts, unless otherwise stated in remarks.

[3]Recovery of at least 1 female of released species was made a year after last release, constituting a tentative establishment.

[4]Establishment not substantiated later.

[5]For other details, see Van Steenwyk and Stern (1977).

EVALUATION PROCEDURES

It is becoming increasingly clear that biological control projects should include plans for evaluating the degree of control obtained. Not only are cost-benefit data from previous programs often essential for approval of new project proposals, but it is frequently necessary to prove that biocontrol agents have actually been the control factor responsible for the reduced importance of a former pest insect. This task is neither simple nor easy, because it is not practical in most instances to provide valid "control" (natural enemy-free) plots side by side with "treatment" plots in the field, as is commonly done in chemical or cultural comparisons.

Fortunately, long-term studies and an indirect approach will usually provide adequate data. "Baseline" data on pest abundance should be collected for a minimum of 3 years prior to the establishment of an introduced natural enemy. Crop damage and yield data are also desirable if not already available. Several years' data are required to allow for fluctuations in pest density, weather effects, and other variables beyond the experimenter's control.

The same data should be collected for several years after the natural enemy has become firmly established. Continued observations are very important because usually 3 to 5 years are required for the biotic agents to become abundant and, in turn, for the pest population to fall to a new, lower equilibrium level. Establishment of additional natural enemy species later, which is desirable if the first species fails to provide sufficient control, would prolong this evaluation period.

To determine whether there are native parasites, as there were for most of the mirids discussed here, parasitism data must also be collected prior to establishment of the exotic species. As outlined earlier, these data must be obtained by two methods--dissections for accurate parasitism percentages and rearing for identification of parasite species. Collection of both types of parasite data must be continued during the postestablishment period. Ideally, parasite reproduction and in some instances the addition of new parasite species will gradually increase the proportion of the target mirid population that is parasitized, and concurrently the mirid will become much less abundant.

AN ASSESSMENT OF THE PROJECT

Progress has been uneven. At least satisfactory numbers of three of the four braconid parasites have been received from Europe, and new methods are being used there to obtain larger quantities of the fourth species, Peristenus adelphocoridis. Adequate numbers of two parasite species have been released in two or more different locations or environments and of the third species in one location. Although diapause problems have allowed only one species to be multiplied in the laboratory, large numbers have not generally been essential for establishment of other parasite species in the past.

Initial difficulties in obtaining reasonable survival of the three parasites and a native species that diapause for extended periods have been overcome, enabling the rearing of much larger numbers for establishment determinations.

There has been some concern that introduced parasites of phytophagous mirids might also attack predatory mirids in North America. Careful work in the laboratory by Porter (1979) has shown that a much wider host range occurs in the laboratory for Peristenus stygicus compared to available field data. However, the actual host range in nature is considerably more restricted, as indicated by the failure of this or any of the other exotic parasites so far to establish even on the same plant-feeding genus or species that they were originally obtained from in Europe, much

less on predatory species in other genera or families and in different (arboreal) habitats.

This specificity could be the major reason that none of the European parasites of Lygus has yet become established in North America on our two (different) species of Lygus. Because three of these parasites attack at least two different genera (Lygus and Adelphocoris) in the field in Europe (table 5), this was not assumed to be a potential problem. However, host-acceptance laboratory tests by the author (still in progress) suggest that neither Lygus lineolaris nor Adelphocoris lineolatus is an adequate host for Peristenus adelphocoridis, P. digoneutis, or P. rubricollis, and that Leptopterna dolabrata is not an adequate host for P. adelphocoridis.

Different environments and climates have been used to improve the chances for establishment of released parasites (see table 6). Sites have varied within a State (for example, in Arizona, two different elevations were selected) or even between adjacent States (for example, Delaware locations are coastal plain, New Jersey sites are piedmont and appalachian). However, the summer photoperiod is shorter because all release sites in the United States have been considerably farther south than the original collection sites of the parasites in Europe. The importance of day length on the establishment success of Peristenus is not known, but it has not prevented establishment in North America of other exotic euphorine braconids (Microctonus spp.) that have obligatory diapause (Day et al., 1971).

It is important to note that adequate parasite release and recovery attempts have been made only in the Northeast and the Southwest, and the results may be different in another region of the United States.

Parasite releases inside a field cage are occasionally used to reduce dispersion of the parasites and hosts, especially when only small numbers of parasites are available. As far as I am aware, only Alophora (table 6) has been released in this manner.

FUTURE DIRECTIONS

Several more years will be required for two aspects of the work. Both Peristenus adelphocoridis and P. rubricollis should be released in larger numbers in the Northeast. Monitoring of release sites must continue for all species for at least 3 years after the last release to detect species that have established but are initially present at very low levels.

Several parasite releases in the Northeast may have failed because of poor synchronization. This has occurred because host nymphs have not always been numerous on the target release dates, which must be planned in advance to schedule parasite emergence from overwintering cocoons. In addition, the exact date of emergence of exotic parasites from their cocoons is usually impossible to predict. It is expected that additional Peristenus digoneutis and P. stygicus specimens will be obtained from collections intended for P. adelphocoridis or P. rubricollis, and they can be used for supplemental releases to obtain better timing.

Possibly some of the failures to establish exotic parasites have been caused by a low incidence of their mating prior to release. The recovery of only males in several instances (table 7; overall 89 percent males) suggests this but could also have resulted from low parasite density in the field, because F_1 or later females were too dispersed to be located by males. Day (unpub.) found that females of Microctonus aethiopoides Loan, a parasite in the same subfamily as Peristenus, usually mate only during the day of emergence; if unmated, all progeny will be males. Accordingly, mating success should be tested for each large lot of field-collected parasites released in the future.

ACKNOWLEDGMENTS[2]

I thank the following individuals for their assistance: R.J. Dysart, L.R. Ertle, and K.S. Swan (BIRL) for shipment, release, and recovery data; L.B. Saunders (BIRL) for technical assistance; R.W. Fuester (BIRL) for advice on parasite identification, rearing, and biology; R.C. Hedlund, D. Coutinot, and H. Hoyer (EPL) for European parasites; C.C. Loan (CDA) for parasite identifications and biological information; J.S. Kelleher (CDA) for European parasites and biological and shipment data; H.M. Graham (BCIL) for parasitism information; J.W. Debolt (BCIL) for parasites and shipment and release data; J.J. Drea, Jr. (BIL) for biological information; K.P. Carl (CIBC-Delémont) for parasite information; N.E. Woodley (SEL) for identification of tachinid parasites; and T.J. Henry (SEL) and J.D. Lattin (Oreg. State Univ.) for identification, references, and biological information on the mirid hosts.

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[2] BCIL = ARS Biological Control of Insects Laboratory, Tucson, Ariz.; BIL = ARS Beneficial Insects Laboratory, Beltsville, Md.; BIRL = ARS Beneficial Insects Research Laboratory, Newark, Del.; CDA = Canada Department of Agriculture, Ottawa; CIBC = Commonwealth Institute of Biological Control, Delémont, Switzerland; EPL = ARS European Parasite Laboratory, Sevres (now Orgerus-Béhoust), France; SEL = ARS Systematic Entomology Laboratory, Washington, D.C.

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BIOLOGICAL CONTROL OF LYGUS BUGS ON VEGETABLE AND FRUIT CROPS

By D.R. Scott[1]

Only plant bugs of the genus Lygus Hahn, as described and restricted by Kelton (1975), are considered here. Other species of closely related genera, for example, Adelphocoris lineolatus (Goeze), or species of Lygus indigenous to the other continents, such as Lygus rugulipennis Poppius, will cause the same type of damage and affect many of the same crops. In North America, 34 of the 43 recognized species of this genus occur. Of these 34, Lygus lineolaris (Palisot), L. hesperus Knight, L. elisus Van Duzee, and L. desertinus Knight are the most important economically.

Some of the vegetables and fruits that are plant hosts of lygus bugs are listed in the appendix. Based on information about hosts of these plant pests, two hypotheses can be made. First, probably most plants used as vegetables and fruits by humans may be damaged by these insects if the circumstances are right. Second, although the four economic species of Lygus mentioned here are responsible for most of the damage reported, other species can and will inflict the same type of damage under different conditions. These species include, but are not limited to, Lygus robustus (Uhler), L. atriflavus Knight, L. nigrosignatus Knight, L. ravus Stanger, and L. shulli Knight. According to some authors (Fisher and Shull, 1942; Frick, 1972), these species can inflict the same type and degree of damage as any of the four economic species. Also, they share many of the same hosts (Domek and Scott, 1985). Whether they inflict damage on any vegetable or fruit crop is probably an accident of proximity.

The four major species dominate lygus bug populations at the lower altitudes, possibly to 500 m, by as much as 99 percent (Fye, 1980, 1982; Domek, 1982). As the altitude increases, this dominance decreases. At 762 m, L. atriflavus is the dominant species in alfalfa (Fisher and Shull, 1942). Above 1,200 m, the four major species are almost absent, with the other five--L. robustus, L. atriflavus, L. nigrosignatus, L. ravus, and L. shulli--becoming dominant (Domek, 1982). Since most of the U.S. vegetables and fruits are grown below 1,200 m, few reports of damage by these five species are in U.S. crop protection literature. Higher latitudes have much the same effect on flora and fauna as higher altitudes; therefore, more reports of damage to all crops by Lygus species other than the four dominant ones are present in Canadian literature.

Lygus bugs are among the most insidious pests of vegetables and fruits. These insects are especially troublesome in that much of their damage may go unnoticed, especially in the seed crops. The effect of lygus bugs on fruit was noticed for many years before the magnitude of their damage to seed crops was known.

"Catfacing" of peach and "apical seediness" of strawberries are deformities that are apparent when the fruit matures, if not earlier. Reduction of seed yields is not so readily apparent, especially if no "uninfested control" yields are available for comparison. The research of Sorenson (1932) on alfalfa and Shull (1933) on beans paved the way for elucidating the effects of Lygus on seed yields. Flemion et al. (1949) pioneered the investigations of the effects of lygus bugs on seed germination and the reasons for those effects. Following these early reports, many investigators have reported on the effects of feeding on vegetable and fruit crops.

Lygus bugs, as well as some other mirids, are especially devastating to seed crops because they tend to concentrate their feeding on developing flowers and seeds. When feeding, they inject a toxic substance, which tends to liquefy

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plant cell contents so that they can be ingested by the insect (Hori, 1976). Some of this toxic substance undoubtedly remains in the plant and results in a small necrotic spot at the site of stylet insertion. However, the salivary secretion also contains a growth-promoting factor. This factor causes increased growth around the original necrotic spot of stylet insertion (Hori, 1976).

When the embryo of the seed is not affected by the initial effects of lygus bug feeding, the growth-promoting substance apparently stays in the seed. Plants grown from such seeds, for example, beans and carrot, are more vigorous and produce more than plants grown from seeds not fed on (Scott, 1970). The growth-promoting substance apparently has some effect on the concentration of indole acetic acid. At least carrot seed developed on lygus bug-infested umbels may have as much as a ninefold increase of the acetic acid compared with seeds not exposed to feeding during development (Scott, 1983). Also a proteinase inhibitor inducing factor (PIIF) apparently may be increased following feeding by Lygus hesperus (Scott, 1983). This PIIF may also cause increased indole acetic acid content. PIIF could inhibit a factor that destroys or "ties up" the acetic acid and thus results in higher levels in the seed.

PLANT HOST REQUIREMENTS

Apparently lygus bugs will attack many species of plants. However, a succession of plants in the reproductive stage through the spring and summer is required to develop damaging populations (Domek, 1982). Alternatively, host sources such as alfalfa or carrot, which flower continuously once bloom is initiated, serve as a substitute for the host sequencing (Domek, 1982).

According to Butler (1968), L. hesperus cannot reproduce on alfalfa while it is in the vegetative phase. (Presumably other Lygus species and plant hosts may have the same limitation.) Spraying the plant with a sugar solution apparently satisfies the insects needs, and they will then reproduce. Butler suggested that aphid honeydew could serve the same purpose. On carrot, L. hesperus and L. elisus only oviposited in flowering umbels. No nymphs hatched in umbels collected at the petal fall stage or later (Scott et al., 1966). This indicates that lygus bugs will only utilize plants as oviposition sites during a short time in the plant development. In the laboratory, these pests will oviposit in bean or lentil pods or other plant parts. Possibly they may do so in the field in the absence of preferred sites.

In an intensive study of lygus bugs and their host plants, few were found on plants that were not in the reproductive stage (Domek, unpub.). Of those records of hosts that were not in this stage, most lygus bugs were on mullein, Verbascum thapsus L., in the late fall and early spring (Domek, 1982). Apparently this plant is an important overwintering host. Since it is a biannual with succulent foliage in late fall, it can provide sustenance when most host plants are dead (McAtee, 1924).

Much has been reported concerning the role of "weed" hosts in Lygus population buildup, especially in the spring (Stitt, 1949; Malcolm, 1953; Fye, 1980, 1982). However, few articles mention the role of these hosts as primary attractants for parasites and predators (Taksdal, 1961). This attractiveness could be both good and bad for Lygus control on crops. A buildup of natural enemies may reduce or "brake" lygus bug population buildup and thus leave fewer to migrate to the food crops. Conversely, if these "weed" hosts were close to the food crop, most of the parasites would be searching these plant hosts for their prey. Strip-cutting alfalfa (Stern, 1976) did impinge on the idea of keeping natural enemies of Lygus in the desired crop.

PROSPECTS FOR BIOLOGICAL CONTROL

The classical definition of biological control is that method that uses such natural enemies as parasites, predators, and diseases to achieve a measure of pest control. That is the context in which it is discussed here. However, a gray area exists, which could include the use of sprays or dusts to keep natural enemies on, or attract them to, crops to be protected. Somewhat allied, but even further removed from biocontrol, is genetic control, especially biogenetic engineering.

A thorough discussion of the native and introduced parasites of lygus bugs has been presented elsewhere in this publication. Since little can be added as far as the natural enemies of *Lygus* pests of vegetable crops are concerned, this discussion is mainly confined to some of the philosophical and other aspects of possible biocontrol of *Lygus*.

Schuster (p. 14) wrote that "...predators...have not been extensively evaluated...but the literature contains numerous references to...predation by both insects and spiders...." In the intensive study by Domek and Scott (1985), Domek observed aphid-tending ants, crab spiders, and asilid flies with *Lygus* prey. Furthermore, he observed that lygus bugs were not present on plant hosts when the aphid-tending ants were, although the lygus bugs were on nearby plants free of ants. Also, Tamaki (pers. commun.) reported that big-eyed bugs, *Geocoris* sp., were effective predators of early nymphal stages of lygus bugs, but not of more mature stages. Damsel bugs, *Nabis* spp., were effective against all stages, but males were less so than females. The spined assassin bug, *Sinea diadema* (F.), was an effective predator, but it also preyed on many beneficial insects.

Native Species of Natural Enemies

These species have evolved with the native *Lygus* species and their plant hosts on this continent for millions of years. During those years, many genetic mutations occurred in all three groups--the natural enemies, the *Lygus* species, and their plant hosts. Many of these mutations had no effect on the natural enemy-lygus bug symbiosis. However, a few probably occurred that had some effect on that relationship, either detrimental to or favorable for the survival of the natural enemy. One of those that favored the natural enemies apparently was involved in their searching capability. Apparently, survival of the natural enemies was higher when they could identify the possible host plants of *Lygus* bugs and then search those plants.

With human introduction of many plants, accidental (such as *Anthemis cotula* L., *Hypericum perforatum* L.) or purposeful (most of the vegetables and fruits), the original "search mechanism" of the natural enemies would not lead them to the introduced plant species. The parasites mostly flew over the introduced species and concentrated on the native plant hosts (Taksdal, 1961). On the other hand, the lygus bugs, being "fast food connoisseurs" (Domek, 1982), made the switch and utilized many of these new plant species as hosts. In one study of *Lygus* species and their plant hosts (Domek and Scott, 1985), about half of the 70 plant hosts utilized for food or oviposition were introduced.

When European settlers introduced their food plants and did not utilize native plants, the stage was set for the high pest status of *Lygus* species. Taksdal (1961) reported that *Lygus lineolaris* was parasitized less than 5 percent on an introduced crop, whereas in adjacent native "weeds," the same species of *Lygus* had a 30 percent parasite infestation. A consistent 30 percent reduction of lygus bugs in our food, fiber, and forage crops would eliminate or drastically reduce the *Lygus* problem.

Introduced Species

Several exotic parasites of *Lygus* bugs and related species have been introduced into the United States. This program

has not met with great success. Again, the millions of years of coevolution of the parasite with its host and its host plant provide the answer. The introduced parasites are well equipped to search the vegetable and fruit crops for their prey. They may do well with the Lygus species in their native lands, as Lygus rugulipennis, but their phytogenetic development has not equipped them to deal with, to them, exotic hosts, apparently. Possibly the mechanisms developed for successful attack on the Lygus spp. in their geographic area do not work on these "exotic" hosts. One must wonder at the damage that L. lineolaris might inflict on the crops in Europe.

ATTRACTANTS

Techniques to attract and keep natural enemies can be called the use of attractants to control pests. When these attractants come from host plants or host insects, this practice verges on biological control. Hagen and Hale (1974) reported on the use of food sprays to attract and keep populations of predators when the populations of their natural prey were low. Their technique has not been very successful.

A technique that might have value would be to protect crops with a spray of ground, or synthesized, material from a preferred native host of lygus bug. If successful, the attractive ingredients could be synthesized on a large scale. The complex relationships between host plants, phytophagous insects, and insect parasites are detailed by Price (1975).

BIOGENETIC ENGINEERING

This topic would normally be under genetic control. However, when the objective is to engineer a more efficient parasite, then it is also biocontrol. The dilemma facing biocontrol of lygus bugs--that of native parasites searching noncrop hosts or that of exotic parasites not able to complete development on native species of Lygus--may be solved by genetic engineering. Two approaches to the problem could be undertaken. First, the genes in the exotic parasites that are involved in searching for plant hosts of their prey could be identified and transferred into the most efficient of the native parasites. Second, the genes in native parasites that are responsible for successful parasite development in native species of Lygus could be identified and transferred into exotic parasite species. Thus biogenetic engineering could proceed along two paths that would require intensive study of the genes in both native and exotic parasites.

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APPENDIX

This is an annotated listing of vegetables and fruits used as hosts by *Lygus* spp. The numbers in parentheses refer to citations at the end.

Host	*Lygus* spp.
Apple: *Malus sylvestris* Mill.	*elisus* (1), *hesperus* (20), *lineolaris* (26)
Apricot: *Prunus armeniaca* L.	*hesperus* (30)
Artichoke: *Cynara scolymus* L.	*hesperus* (30)
Asparagus: *Asparagus officinalis* L.	*hesperus* (30), *lineolaris* (8)
Bean, broad: *Vicia faba* L.	*hesperus* (30)
Bean, garden: *Phaseolus vulgaris* L.	*desertinus* (21), *elisus* (32), *hesperus* (30), *lineolaris* (11), (17)
Bean, lima: *P. lunatus* L.	*hesperus* (30), *lineolaris* (23)
Beet: *Beta vulgaris* L.	*desertinus* (21), *elisus* (32), *hesperus* (30), *lineolaris* (26)
Broccoli: *Brassica oleracea* L.	*lineolaris* (26)
Cabbage: *B. oleracea* L.	*hesperus* (30), *lineolaris* (26)
Carrot: *Daucus carota* L.	*elisus* (32), *hesperus* (30), *lineolaris* (7)
Celery: *Apium graveolens* L.	*atriflavus* (15), *hesperus* (30), *lineolaris* (18)
Cherry: *Prunus* sp.	*lineolaris* (19)
Chicory: *Cichorium intybus* L.	*atriflavus* (14), *elisus* (14), *hesperus* (14), *ravus* (14), *robustus* (14), *shulli* (14)
Chokecherry: *Prunus virginiana* L.	*lineolaris* (26)
Corn, sweet: *Zea mays* L.	*hesperus* (30), *lineolaris* (24)
Cucumber: *Cucumis sativus* L.	*hesperus* (30), *lineolaris* (8)
Currant, black: *Ribes nigrum* L.	*lineolaris* (26)
Dill: *Anethum graveolens* L.	*elisus* (29), *hesperus* (30)
Eggplant: *Solanum melongena* L.	*hesperus* (30)
Endive: *Cichorium endivia* L.	*lineolaris* (6)
Escarole: *C. endivia* L.	*lineolaris* (6)
Fig: *Ficus carica* L.	*hesperus* (30)
Horseradish: *Armoracia rusticana* Gaertn., Mey., & Scherb.	*lineolaris* (26)
Lentil: *Lens culinaris* Medik.	*elisus* (25), *hesperus* (25), *robustus* (25)
Lettuce: *Lactuca sativa* L.	*hesperus* (30), *lineolaris* (26)
Mustard: *Brassica juncea* (L.) Czern. & Coss.	*borealis* (Kelton) (20), *lineolaris* (22), *nigrosignatus* (20)
Onion: *Allium cepa* L.	*lineolaris* (31)
Parsnip: *Pastinaca sativa* L.	*hesperus* (30)
Pea, black-eyed: *Vigna unguiculata* (L.) Walp.	*hesperus* (30)
Pea, garden: *Pisum sativum* L.	*hesperus* (30), *lineolaris* (9)
Peach: *Prunus persica* (L.) Batsch	*elisus* (3), *hesperus* (30), *lineolaris* (13), *nigrosignatus* (20)
Pear: *Pyrus communis* (L.)	*elisus* (1), *hesperus* (30), *lineolaris* (4)
Pecan: *Carya illinoensis* (Wangenh.) K. Koch	*lineolaris* (12)
Pepper: *Capsicum annuum* L.	*hesperus* (30), *lineolaris* (23)
Peppermint: *Mentha piperita* L.	*elisus* (21), *hesperus* (30), *nigrosignatus* (21)
Plum: *Prunus* spp.	*lineolaris* (27)
Potato: *Solanum tuberosum* L.	*elisus* (21), *hesperus* (30), *lineolaris* (18)
Prune: *Prunus domestica* L.	*lineolaris* (28)
Radish: *Raphanus sativus* L.	*hesperus* (30)
Raspberry, red: *Rubus idaeus* L.	*lineolaris* (5)

Sesame: Sesamum indicum L.	hesperus (30)
Spinach: Spinacia oleracea L.	elisus (33), hesperus (30) lineolaris (10)
Squash: Cucurbita spp.	lineolaris (11), (16)
Strawberry: Fragaria spp.	hesperus (30), lineolaris (26), shulli (32)
Sunflower: Helianthus annuus L.	desertinus (14), elisus (14), hesperus (14)
Sweetpotato: Ipomea batatas (L.) Lam.	hesperus (30)
Swiss chard: Beta vulgaris L.	lineolaris (26)
Tomato: Lycopersicon esculentum Mill.	elisus (2), hesperus (30), lineolaris (26)
Turnip: Brassica rapa L.	hesperus (30), lineolaris (26)
Watermelon: Citrullus lanatus (Thunb.) Matsum & Nakai	hesperus (30)

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BIOLOGICAL CONTROL EFFORTS ON MIRIDAE IN CANADA

By C. Harvey Craig and Conrad C. Loan[1/]

Although many species of the family Miridae (Heteroptera) are economically important pests of field, fruit, and vegetable crops, they have only recently received attention in Canada as targets for biological control. Research was undertaken to integrate a biological component into ongoing control programs for mirid pests of alfalfa grown for seed in western Canada and of vegetables in Quebec. To date, emphasis has been on certain species of Lygus Hahn and the alfalfa plant bug, Adelphocoris lineolatus (Goeze), and their associated euphorine parasites, Peristenus Foerster.

BIOCONTROL AGAINST *LYGUS*

In western Canada, the species of Lygus most abundant on alfalfa include L. borealis (Kelton), L. lineolaris (Palisot), L. desertinus Knight, L. unctuosus (Kelton), and L. elisus Van Duzee (Kelton, 1975). South of about latitude 50° N. these species are partially bivoltine; about 70 percent of the summer adults become reproductive and produce a second generation. Progressively northward a smaller proportion of summer adults becomes reproductive, until north of latitude 53°30' N. no summer adults become reproductive in the same year and the species are entirely univoltine (Craig, 1983).

In the agricultural regions of eastern Canada, the dominant species on alfalfa is L. lineolaris, which is largely bivoltine, with about 88 percent of summer adults becoming reproductive (Guppy, 1958; Loan, 1965).

Euphorine (Braconidae) parasites indigenous in the Lygus population in Canada are Peristenus (formerly Leiophron) pallipes (Curtis) and P. pseudopallipes (Loan). In Ontario, P. pallipes attacks first-generation nymphs feeding on forage legumes, and P. pseudopallipes attacks second-generation nymphs feeding mainly on several weed species. The incidence of parasitism was 45 to 60 percent by P. pallipes in the first generation and 8 to 12 percent by P. pseudopallipes in the second generation, with good host-parasite synchrony (Loan, 1965, 1970, 1980). In southwestern Quebec, the incidence of parasitism in L. lineolaris by combined P. pallipes and P. pseudopallipes was 7 percent in a weedy habitat and 4.7 percent in an alfalfa habitat; host and parasites were not well synchronized in that area (Lim and Stewart, 1976a).

In the prairie area of western Canada, parasitism of first-generation Lygus spp. by P. pallipes averaged 22 percent (Loan and Craig, 1976) and 34 percent (Moline, 1983). Euphorine parasitism has also been confirmed in the second generation, but the parasite species is not known (Moline, 1983; Craig, unpub.). Maximum parasitism in both generations is coincident with peak host nymphal population, an indication of good synchrony (Moline, 1983). In Lygus populations from 43 southern Alberta alfalfa seed fields, in which parasitism ranged from 2 to 83 percent, no correlation was found between the maximum level of parasitism in the first host generation and the numerical size of the second host generation (Moline, 1983).

Loan (1965) briefly described the development of P. pallipes on several mirid hosts and outlined its life history in Leptopterna dolabrata (L.). The parasite oviposits in second-, third-, and occasionally in fourth-instar nymphs, and development time is 5 to 6 weeks in the field. The mature larva emerges from either the fifth-instar nymph or the adult. The larva spins a cocoon in the soil and development proceeds to the late pupal stage. The pharate adult diapauses in the cocoon and emerges the following spring.

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Lim and Stewart (1976a, b), working at MacDonald College, Quebec, reported seasonal similarities and differences in parasitism of L. lineolaris by both P. pallipes and P. pseudopallipes in weedy and alfalfa habitats. They reported further on laboratory development of these two species, with particular attention to a description of the immature stages of P. pseudopallipes. Broadbent (1976), also of MacDonald College, conducted laboratory studies on the biology of an imported parasite, Peristenus stygicus Loan. He concluded that this species possesses many desirable qualities for Lygus control, such as facultative diapause, relatively short developmental time, long adult lifespan, high level of parasitization, and ease of mass rearing.

A program to augment the native parasitism in Lygus populations in western Canada by introducing euphorine parasites of European origin was started in 1977-78. A contract was made with the Commonwealth Institute of Biological Control, European Station, Delémont, Switzerland, to supply the parasites. Peristenus spp. were reared to the cocoon stage at Delémont from the host Lygus rugulipennis Poppius collected from alfalfa and red clover near the Tullner Feld, Austria. Cocoons were shipped, usually in the fall, to the Biocontrol Unit of Agriculture Canada, Ottawa, for quarantine and overwintering, and in the spring for rearing to adults under controlled conditions. Because of limited resources at Saskatoon and other considerations, the direct release method of introduction was adopted. The synchrony of adult parasite emergence and release with optimum first-generation host development was of prime importance, and in most instances this was achieved. The sites selected for parasite release were established alfalfa seed production fields in several ecologically different locations in Saskatchewan and Alberta. During 1978-81, 1,960 P. digoneutis Loan and 64 P. stygicus specimens were released (table 1). Their lifespan at the liberation sites for monitoring purposes was about 5 years. During that time they were subject to normal seed production management practices, except insecticide treatment.

The following three methods were used to detect the presence of euphorine parasites: (1) Alfalfa and nearby host plant vegetation at the liberation sites were sampled by sweep net to recover parasite adults. In three seasons' sampling, 1980-82, only 70 adults were captured and all were the native species P. pallipes.

(2) Late-instar Lygus nymphs were mass collected from the sites and reared in cages in a controlled environment to obtain parasite cocoons. A technique similar to that of Van Steenwyk and Stern (1976) was used, with about equal success in utilizing either a felt strip maze or peat moss as the cocooning medium. Adult emergence from the cocoons has been very inconsistent from year to year and even from lot to lot. Several combinations of duration and temperature of cold treatment to break diapause and various incubation temperatures and humidities have been tested to improve emergence. Inconsistencies still exist, but up to 85 percent emergence has been achieved with a cold treatment of 210 days at 2°C followed by an incubation period of 25 to 50 days at 22°. Also, from nonemerged cocoons the pharate adult can be excised and identified. This method of rearing and excision has yielded about 1,300 adults in the 3 seasons. All specimens obtained to date are the native parasite P. pallipes.

(3) At least once each season, and always just prior to each release of imports, samples of not less than 200 Lygus specimens from the sites have been dissected for parasite presence. From 1979 through 1983, during and since the introductions, the incidence of parasitism has not changed, averaging 20 percent overall within a range of 1.6 to 50 percent and with no obvious increase at any individual release site. After 4 years' introductions (1978-81), followed by 3 years' monitoring (1980-82), there is no evidence that the introduced parasites have become established.

Table 1
Liberations of Peristenus spp. in alfalfa against Lygus spp. and Adelphocoris lineolatus (Goeze) in western Canada

Date of liberation	Location of liberation site	Species	Number
	Lygus spp.		
1978			
June 7	Moose Jaw, SK; 50° N.; shortgrass prairie; dry	P. digoneutis	197
June 9, 13, 21	Saskatoon, SK; 50° N.; mixed prairie; dry	P. digoneutis	177
1979			
June 14, 21	Tilley, AB; 50°30' N.; shortgrass prairie; irrigated	P. digoneutis P. stygicus	541 41
June 29	Shellbrook, SK; 53° N.; parkland-mixed forest; dry	P. digoneutis P. stygicus	159 23
1980			
May 30	Ardath, SK; 51°30' N.; mixed prairie; dry	P. digoneutis	167
	Saskatoon, SK; mixed prairie; irrigated	P. digoneutis	80
June 3	Shellbrook, SK; (supplement to 1979 release)	P. digoneutis	261
June 10	Saskatoon, SK; (supplement to 1978 release)	P. digoneutis	138
1981			
June 12	Yellow Creek, SK; 53° N.; parkland; dry	P. digoneutis	125
	Saskatoon, SK; (supplement to 1980 release)	P. digoneutis	115
	Adelphocoris lineolatus (Goeze)		
1980			
July 2	Clavet, SK; 52° N.; mixed prairie; dry	P. adelphocoridis	47
	Lygus spp.		
July 8	Shellbrook SK; 53° N.; parkland-forest; dry	P. adelphocoridis P. rubricollis	29 49
1981			
June 5	Saskatoon, SK; 52° N.; mixed prairie; dry	P. adelphocoridis	23
June 12	Yellow Creek, SK; 53° N.; parkland; dry	P. adelphocoridis	16
June 26	Shellbrook, SK; (supplement to 1980 liberations)	P. adelphocoridis	12

The work on parasitism in Lygus and other Peristenus biological studies under R.K. Stewart at MacDonald College was largely discontinued in the late 1970's. At the Saskatoon Research Station, no further introductions of Lygus parasites are planned at this time. Site and vicinity monitoring will continue on a modest scale to detect any indication of parasite establishment.

One of the major constraints to research on Lygus, particularly in areas and on host plants where a complex of species occurs, is the lack of nymphal taxonomy for the genus. The major problem in rearing Peristenus parasites is spotty and inconsistent adult emergence from the cocoon. The key factors that initiate emergence in the pharate adult are still unknown for diapausing Peristenus species.

BIOCONTROL AGAINST *ADELPHOCORIS LINEOLATUS* (GOEZE)

The alfalfa plant bug, Adelphocoris lineolatus, a native insect of Europe and western Asia, was introduced into North America at Cape Breton, Nova Scotia, Canada, about 1917. In the succeeding 50 years, it spread westward through agricultural areas of eastern and central Canada to the foothills of the Rocky Mountains in western Alberta (Craig, 1971). Throughout its range of distribution south of about latitude 50° N., the species is largely bivoltine, with two complete generations a year in southern Ontario (Guppy, 1958; Loan, 1965), whereas in western Canada some individuals of the second generation do not reach maturity (Craig, unpub.). North of about latitude 53° N., the species is largely univoltine; only about 5 percent of the eggs hatch the year they are laid and no second-generation individuals reach maturity (Craig, 1963).

Adelphocoris lineolatus is an important pest of alfalfa seed production. Because it overwinters in the egg stage, peak nymphal populations occur earlier in the season than Lygus, at about the time that alfalfa is coming into flower bud. Damage is most severe to the flower buds (bud blast) and to the early blossoms. A population of 12-15 late-instar nymphs per 180° sweep of a 38-cm net can prevent an alfalfa crop from blooming. This insect reproduces on other forage legumes such as sainfoin and trefoil, but its injury to these crops has not been evaluated.

In the early 1960's at Belleville, Ontario, and in northern Saskatchewan, first-generation nymphs of A. lineolatus were found to be parasitized by Peristenus pallipes. The incidence, determined by dissection of nymphs, ranged from 40 to 60 percent in Ontario to 3 percent in Saskatchewan (Craig, 1963; Loan, 1965). From 1976 to 1980, the incidence of euphorine parasitism averaged 0.3 percent, with a range of 0 to 4 percent in midwestern populations. Only nymphs of the first generation were parasitized; those of the second generation, where parasitism occurs, were entirely parasite-free, as were the adults. No other nymphal parasites have been found.

Adelphocoris lineolatus, because of its recent introduction to North America from Europe without its specific parasite, Peristenus adelphocoridis Loan (Loan, 1979) or other parasite species, is considered to be an excellent candidate host for imported biocontrol agents. Consequently, the Delémont Station of the Commonwealth Institute of Biological Control has been requested to supply parasites in sufficient quantity for direct release into A. lineolatus populations in western Canada.

In the summers of 1979 and 1980, A. lineolatus nymphs were collected in eastern Austria and reared at the Delémont Station. Parasite cocoons from these rearings were sent to the Biocontrol Unit of Agriculture Canada, Ottawa, for quarantine, overwintering, and subsequent completion of rearing. In the spring of 1980, two species, Peristenus adelphocoridis and P. rubricollis (Thomson), emerged from these cocoons. In the 1981 rearings, only P. adelphocoridis was present. The

adult parasites were shipped to the Saskatoon Research Station for release in western Canada. A total of 127 P. adelphocoridis and 49 P. rubricollis specimens were released directly into A. lineolatus populations in alfalfa seed fields (table 1).

Because of erratic emergence of parasite adults, the 1980 releases were not well synchronized with A. lineolatus development. This, and the few individuals released in the 2 years, greatly reduced the likelihood of establishment. From about 3,000 first-generation A. lineolatus specimens collected at the release sites in 1981-82, only 17 parasite cocoons were obtained. No adults emerged, and 14 pharate adults excised from these cocoons were all P. pallipes.

Constraints to this parasite introduction program have been the lack of a technique for continuous rearing of A. lineolatus and the difficulty of obtaining the large quantities of parasites in Europe that are required for the direct release method of introduction. Consequently, the research emphasis, under K.P. Carl at Delémont, has latterly shifted to biological parameters in the European Adelphocoris-Peristenus association in both the laboratory and the field, with the objective of developing techniques to obtain parasites in sufficient quantity for direct release in western Canada. Considerable progress has been made, and parasites may be available for 1985 introductions (Carl, 1983).

ACKNOWLEDGMENTS

The authors acknowledge with thanks the contributions to content and manuscript review by A.P. Arthur and L. Burgess, Agriculture Canada, Saskatoon, Saskatchewan; J.R. Coulson, ARS, Beltsville, Md.; J.C. Guppy and J.S. Kelleher, Agriculture Canada, Ottawa, Ontario; D.K. Moline, Creston, British Columbia; and R.K. Stewart, McGill University, Montreal, Quebec.

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TAXONOMIC STATUS, BIOLOGICAL ATTRIBUTES, AND RECOMMENDATIONS FOR FUTURE WORK ON THE GENUS *LYGUS* (HETEROPTERA: MIRIDAE)

By Thomas J. Henry and John D. Lattin[1/]

Species of Lygus, frequently called lygus bugs, are the most important agricultural pests in the plant bug family Miridae (Heteroptera). The tarnished plant bug, Lygus lineolaris (Palisot), occurring over most of North America, is a pest of cotton in the Southern United States. In the Western United States, several species attack alfalfa and cotton. Because of the severe damage these plant bugs inflict, an extensive search has been implemented by the U.S. Department of Agriculture and cooperating agencies for natural enemies, especially nymphal parasites in the wasp family Braconidae. This report is an overview of the taxonomic status of the genus Lygus to help biological control researchers better understand the taxonomy of Lygus and the taxonomic problems related to controlling this pest group.

The plant bug genus Lygus in North America contains several economically important species. They feed on a variety of crops and native plants. Some species are widely distributed and broadly overlap the ranges of others. Great morphological variation in adults often makes positive identification difficult. At least some species of Lygus are parasitized regularly by Braconidae, chiefly in the nymphal stages. Positive identification of Lygus nymphs except in rare instances is not now possible. The variations caused by seasonal factors, the variety of host plants, and genetic factors, coupled with the problem of identifying nymphs to species, contribute to the difficulty in accurately assessing important economic problems.

ORIGIN OF PEST SPECIES

Pest status varies with the organism and resource being evaluated. Acceptable population levels may be low when dealing with disease vectors (Burgess et al., 1983) or much higher when considering certain defoliators. The pest problem then is a relative state dependent on the circumstances. Norton and Conway (1977, p. 205) provided a useful definition: "A pest problem is, therefore, characterized not only by the state of the pest population itself but, more importantly, as the damage or illness it causes and the value placed on these consequences by human society." Several Lygus spp. are considered pests because their feeding damage on certain crops is unacceptable to those involved in crop production (Graham et al., 1984). This damage often is enhanced because lygus bugs frequently feed on reproductive parts of the plant and thus are frequently pests of seed crops (Burgess et al., 1983).

Some Lygus spp. have become pests because they are usually highly mobile, multivoltine, and oligophagous (r-selected), feeding on new growth and reproductive parts. In contrast to many other insect pests in North America, these species are native insects attacking a large array of introduced crops, except in a few instances, such as an Oregon species that feeds on native Limnanthes (meadowfoam) (J.D. Lattin, pers. observ.) and a California species that attacks guayule (Romney, 1946; Bolton et al., 1972; Lattin and Oman, 1983). Price (1976), Southwood (1977), and others have pointed out that many pest herbivores are r-selected species, and in the disturbed environments typical of most agroecosystems, such species can often colonize faster than their predators and parasites. Southwood (1977) stated that polyphagous predators are likely to be important in such habitats. The heteropteran family Nabidae contains several very common, polyphagous predators found frequently in such disturbed habitats in North

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America, for example, Nabis alternatus Parshley and N. americoferus Carayon (Graham and Jackson, 1982).

Lygus bugs, highly mobile as adults, often move from disturbed habitats into crop fields (Fye, 1980). Some species migrate from wild to cultivated plants and have been collected at elevations as high as 5,000 ft (Glick, 1939; Johnson and Southwood, 1949). Although most Lygus spp. are normally multivoltine, single generations may occur in the northern part of their ranges (Kelton, 1975; Craig, 1983). At least one species, Lygus unctuosus (Kelton), may have only a single generation (Kelton, 1975; Craig, 1983). Other univoltine species of Lygus, for example, L. vanduzeei Knight, normally are not economically important (Reid et al., 1976). Care should be taken in determining the actual number of generations (Shull, 1933; Salt, 1945; Craig, 1983).

Feeding occurs most often on growing tips or reproductive parts of the plant, areas of high nutrients. This is particularly damaging to plants grown for seed (Jeppson and MacLeod, 1946; Craig, 1983; Rice et al., 1985). According to Scott (1970, 1983), such feeding might reduce seed yield and germination in carrots, but the plants grown from damaged seed fed on by Lygus spp. may show accelerated growth and larger plants and roots. Conversely, some evidence indicates that such feeding might stimulate increased productivity in some crop species (Scott, 1970). In some instances, the host plant may affect adult longevity and fertility in Lygus bugs (Al-Munshi et al., 1982).

Lygus bugs also feed as scavengers and facultative predators of arthropods. Predation on living insects probably involves moribund individuals or those undergoing ecdysis (Wheeler, 1976). The laboratory rearing of Lygus spp. may be enhanced by adding animal food to the diet (e.g., Bryan et al., 1976).

Several pest species of Lygus are known to occur on a wide variety of plants, both introduced and native (Stitt, 1949; Malcolm, 1953; Parker and Hauschild, 1975; Scott, 1977; Fye, 1980; Snodgrass et al., 1984). Since not all such plant records represent hosts on which eggs are laid, care should be taken to distinguish between hosts, where nymphs occur, and resting or feeding hosts, where only adults are found. Often host plant records in the literature cannot be associated positively with species of Lygus because of the difficulty in making accurate specific identifications and the lack of voucher specimens, particularly in western North America. If voucher specimens have been retained from the numerous economic studies (see Graham et al., 1984), some associations can be verified or corrected. Fortunately the widespread Lygus lineolaris is more easily recognized throughout much of its range than is the complex group of western taxa.

Because legumes frequently are utilized as hosts by North American species of Lygus, it is curious that L. lineolaris, with a large array of hosts (Snodgrass et al., 1984), is not a pest on soybeans, even though this species occurs throughout much of the crop's range and 453 insect species have been recorded from this crop in North America (Kogan, 1981). The establishment and subsequent spread of alfalfa in western North America likely affected significantly the movement and colonization of western species of Lygus bugs (Bolton et al., 1972). The effect of such a crop on the widely scattered, naturally occurring populations of Lygus remains to be studied. When positive species identifications can be combined with accurate host associations, it will be possible to examine the status and distribution of some western Lygus species. This may be an example of "reverse" island biogeography, where a crop plant provides a corridor for dispersal between naturally separated populations.

DEFINITION AND PLACEMENT OF *LYGUS* IN THE FAMILY MIRIDAE

The group of bugs commonly referred to as lygus bugs belongs in the genus Lygus Hahn and to the plant bug family Miridae,

the largest family in the true bug order Heteroptera (superorder Hemiptera). About one-third to one-half of all Heteroptera are mirids. Although fewer than 7,000 species were listed in the Carvalho world Miridae catalog (1957-60), many have been described since the 1950's, probably bringing the total to 10,000 or more. Most mirid workers predict that the species inventory for the world will reach 20,000. Within the Miridae, Lygus is included in the largest subfamily, the Mirinae. According to Carvalho (1957-60), more than 250 mirine genera were described by 1955. Of these, Lygus (sensu lato) contained the greatest number of species, about 300.

Currently, however, only 34 species are placed in Lygus in North America and about 8 are known from the Old World (Kelton, 1975). The reduced number of species recognized in Lygus deserves some explanation. Historically, the broad definition of the Lygus was based largely on the overall similarity of many species, which were inconsistently broken into several similar appearing subgenera. Even so, the economic literature on Lygus was basically stable, and few entomologists were concerned that the pestiferous lygus bugs did not belong in the nominate subgenus Lygus, that is, until more recently, when the type of Lygus became more than an academic problem.

The current classification of Lygus is built primarily on the work of several key workers (appendix). Knight (1917) provided the first comprehensive review of the North American species. He recognized six species groups of Lygus, including his new subgenus Neolygus. China (1941), on discovering that Distant (1904) had designated Cimex pabulinus Linnaeus as the type-species of Lygus, described the subgenus Apolygus (type-species Lygaeus limbatus Fallén) to accommodate what he thought would include Lygus pratensis (L.) and other British "lygus bugs" (China, 1943). Wagner (1949), in a revision of the Palaearctic Lygus, noted that the European L. pratensis was not consubgeneric with species in other subgenera and described the subgenus Exolygus to accommodate it and allies. Leston (1952), in the first attempt to evaluate internal relationships of the genus on a worldwide basis, recognized six subgenera, including his new subgenus Taylorilygus, which contained Lygus pallidulus (Blanchard) (as Lygus apicalis Fieber, a junior synonym) and the African "lygus bugs."

Leston's work served as the basis for an important revision by Kelton (1955a), who, by utilizing male and female genitalia and external morphology, gave strong evidence that most of the subgenera previously placed in Lygus deserved generic status. He recognized as valid genera Agnocoris Reuter (type-species Lygaeus rubicundus Fallén), Liocoris Fieber (type-species Cimex tripustulatus Fabricius) (with Exolygus Wagner as a junior synonym (type-species Cimex pratensis Linnaeus)), Lygus Hahn (type-species Cimex pabulinus Linnaeus), Orthops Fieber (type-species Cimex kalmii Linnaeus), and Taylorilygus Leston (type-species Lygus simonyi Reuter) (appendix). This revision produced the result Slater (1950) had predicted should several subgenera in Lygus be raised to genus, viz, that the economically important lygus bugs would be placed in a genus other than Lygus. Because the North American lygus bugs are congeneric with Cimex pratensis (the type-species of Exolygus), Kelton's revision required that they be transferred to Exolygus. Kelton (1955a, 1955b) considered Exolygus a junior synonym of Liocoris, meaning, that if this interpretation was followed, the lygus bugs would take the generic name Liocoris. Wagner (1957), however, maintained that Exolygus and Liocoris were not congeneric, leaving the status of Exolygus problematic.

To prevent such an upheaval in the economic literature, Carvalho, Knight, and Usinger (1961), with the agreement of most of the mirid-worker community, including Kelton, petitioned the International Commission of Zoological Nomenclature (I.C.Z.N.) to reject Cimex pabulinus as the type of the subgenus

Lygus and to designate Cimex pratensis as the type-species. The I.C.Z.N. (Opinion 667, 1963) thus ruled to preserve the well-known concept of Lygus with the following decisions:

(1) Lygus Hahn, 1833 (fix Cimex pratensis Linneaus, 1758, as the type-species).
Exolygus Wagner, 1949 (type-species Cimex pratensis Linneaus), an objective junior synonym of Lygus to be placed on the list of officially rejected names.

(2) Lygocoris Reuter, 1875 (fix Cimex pabulinus Linneaus, 1761, as the type-species).

These changes have insured that the economic lygus bugs will remain in the genus Lygus and that Exolygus will always be a junior synonym because they have the same type-species. Presently, Liocoris is considered distinct from Lygus, but if Kelton's conclusions are followed, it becomes a junior synonym of Lygus.

GENERIC AND SPECIES RECOGNITION

Nearctic Taxa

Anyone who has tried to identify species of Lygus will agree that the genus is particularly difficult to define. Carvalho (1955) in a monumental effort probably illustrates it best. Of 154 mirine genera in his "Keys to the Genera of the Miridae of the World," Lygus falls out at couplet 153, a clear indication that the genus is most easily diagnosed by eliminating the other more "distinct" genera. Carvalho's study, however, predated Kelton (1955a) and others who published their interpretations of the Lygus complex. Kelton's (1955a) key to genera of the Lygus complex, if used in conjunction with the more comprehensive keys of Blatchley (1926), Knight (1941, 1968), and Kelton (1980) to reach the Lygus complex, will allow relatively easy recognition of the North American genera. Slater and Baranowski's (1978) publication contains the only recent key to genera of North American Miridae. Its simple terminology with numerous illustrations makes it a good generic reference.

At the species level, Kelton's (1975) revision of North American Lygus is the best reference to consult. It contains a key and descriptions of all recognized species, notes on their distribution and hosts, and clarification of earlier misidentifications of Palaearctic species. Although he reevaluated the Nearctic fauna and recognized several synonyms, determination of species remains difficult, even for the specialist with correctly identified specimens for comparison. Most species of Lygus are multivoltine and have numerous seasonal or color forms, which compound the degree of difficulty in species recognition. In table 1 is a summary of overwintering stages, voltinism, and host plant groups of Lygus and associated genera. Current difficulties in associating certain populations of Lygus with specific names indicate that some of the 34 Nearctic species may be conspecific.

Palaearctic Taxa

For the Palaearctic region, several good references can be used to identify genera and species. Southwood and Leston (1959) provided a key to the species and genera of the tribe Mirini found in the British Isles. Stichel's (1958) publication is one of the best for the European species of Miridae. Kiritshenko's (1951) keys to the bugs of the European U.S.S.R., although having an outdated generic scheme, can be used for species identifications. Kerzhner's (1964) key is good for the genera and the species found in the European U.S.S.R.; Vinokurov's (1979) key is available for the more eastern region of Yakut. Wagner's (1970-71) key to the Miridae of the Mediterranean region, although still using the name Exolygus instead of Lygus, is the most recent and comprehensive European reference. As in North America, the species are variable and often difficult to recognize with certainty.

Table 1
General life history and host information of Lygus and other genera previously included in the Lygus complex

Genus	Overwintering stage	Number of generations	Hosts
Agnocoris	Adult	Multiple (?)	Host specific on Salix spp.
Dagbertus	Adult and egg (?)	Multiple	Polyphagous
Lygocoris			
Subg. Apolygus	Egg	Single	Polyphagous (?) weeds and trees
Subg. Lygocoris	Egg	Multiple	Polyphagous
Subg. Neolygus	Egg	Single	Host specific on trees and shrubs
Lygus 1/	Adult	Multiple	Polyphagous
	Egg	Single	Host specific
Orthops	Adult	Multiple (?)	Host specific on Umbelliferae
Pinalitus	Egg	Single	Host specific on Picea and Pinus spp.
Taylorilygus	Adult and egg	Multiple	Polyphagous

1/Appears to have 2 distinct species groups.

IDENTIFICATION OF NYMPHS

Late-instar nymphs of North American Miridae may be recognized using several nymphal keys, including DeCoursey (1971), Herring and Ashlock (1971), and Slater and Baranowski (1978). Southwood (1956) developed a key for determining the instar of cimicomorphan nymphs. Leston and Scudder (1956) gave descriptions and family keys to the nymphs of the British Heteroptera. Butler's (1923) "Biology of the British Hemiptera-Heteroptera" contains descriptions, life histories, and hosts of many species, including those in the Lygus complex found in the British Isles. Bech (1969) should be consulted for information on the life history, ecology, and nymphs and particularly for the long host list of the Palaearctic species of Lygus and related genera. In both of the last texts, an older scheme of classification, similar to that presented by Wagner (1949), is given. Users of these references need to update the generic placement of the species treated.

Akingbohungbe et al. (1973) published the only text containing nymphal keys to the genera of Miridae in North America. Their "Keys to the Nymphs of the Wisconsin Miridae" show that it is possible to recognize genera and even species of Miridae in the immature stages.

RELATIONSHIPS OF GENERA PREVIOUSLY PLACED IN *LYGUS*

Agnocoris Reuter. The Holarctic willow-feeding genus Agnocoris externally is similar to Lygus, but the genital structures, silky pubescence, and short second antennal segment define a

distinct genus (Kelton, 1955a). Although Slater (1950) believed the female genitalia of Agnocoris were rather distinct from those of other Lygus groups (subgenera), Kelton (1955a) suggested that Agnocoris, along with the Palaearctic genus Cyphodema Fieber, was one of the few genera previously placed in the Lygus complex that showed close relationship to Lygus.

Knightomiris Kelton. The parameres of Knightomiris distinctus (Knight) are similar to those of Lygus, but K. distinctus has a prominent tubercle on the margin of the pygophore above the left paramere and the vesica differs in having two distinct spiculi (Kelton, 1974). Kelton erected Knightomiris to accommodate this single species.

Lygocoris Reuter. This genus, now divided into four subgenera, probably has little relationship to Lygus. Slater (1950) indicated that the subgenus Neolygus does not appear even closely related to Lygus. Kelton (1955a) confirmed that male and female genitalia and many external characters linked the subgenera Apolygus, Lygocoris, Neolygus, and Stechus. Based on this information, Kelton considered Lygocoris distinct from Lygus [as Liocoris]. Clayton (1982) further supported the distinctiveness of Lygocoris and suggested that the subgenera Apolygus, Lygocoris, and Neolygus might best be considered as separate genera. Zheng and Wang (1982, 1983) and Wang and Zheng (1982), although apparently correctly placing 20 new species from China in Apolygus, incorrectly placed them in the genus Lygus. As members of the subgenus Apolygus, they must be placed in the genus Lygocoris. Kelton (1971) reviewed the Nearctic species of Lygocoris, redescribed the adults, furnished host plant information, and provided a key to help distinguish species found in Canada and Alaska.

Orthops Fieber. Wagner's (1949) vague definition of Orthops includes a group of heterogeneous species (Kelton, 1955a). Kelton's study of the Palaearctic species visicola (Puton), cervinus (Herrich-Schaeffer), atomarius (Meyer-Dür), and rubricatus (Fallén) indicated that they were not congeneric with kalmii Linnaeus, the type-species of Orthops. Later, the spruce-feeding rubricatus was transferred to Pinalitus Kelton with the pine-feeding approximatus Stål (Kelton, 1977) and three other Nearctic species. Kelton (1955a) considered the umbelliferous-feeding species of the genus Orthops remotely related to Lygus. Orthops is considered closely related to the Afro-tropical genus Lygidolon Reuter, which has been reviewed by Odhiambo (1960), Ghauri (1971), and Linnavuori (1974). Linnavuori (1975) noted that the African species of Lygidolon, Orthops, and Taylorilygus need to be revised and should be studied along with the genera Gutrida Kirkaldy, Oreolygus Linnavuori, and Yngveella Poppius.

Pinalitus Kelton. The genus Pinalitus, erected to accommodate the species approximatus Stål, apparently is related to the Neotropical genus Alda, but it differs in having a much shorter first antennal segment (Kelton, 1955a). Alda resembles certain members of the widely distributed genus Phytocoris Fallén and, like Pinalitus, is not closely related to Lygus.

Proba Distant. The species Lygus sallei Stål, included in Knight's (1917) catchall group I, now is placed in the Neotropical genus Proba. Carvalho (1952) previously considered Paralygus Reuter a junior synonym of Proba.

Kelton (1955a) noted a superficial resemblance of Proba to Horcias Distant (the latter is now in part subdivided, with the North American species transferred to the genus Metriorrhynchomiris Distant (Carvalho and Jurberg, 1974)), but he stated that the absence of a transverse carina between the eyes and the form of the genital structures on Horcias easily separated it from Proba.

Sabactus Distant. Another monotypic genus known from Sri Lanka, it contains only the species institutus (Distant).

Previously this genus was placed in Lygus, but Kelton showed that the two genera are not closely related.

Salignus Kelton. This Nearctic, monotypic genus (Kelton, 1955a) possesses unique characters making it distinct from *Lygus*. *Salignus distinguendus* (Knight), a willow-feeding species, differs in structure from any taxon studied by Kelton (1955a).

Taylorilygus Leston. Kelton (1955a) considered Leston's subgenus *Taylorilygus* a distinct genus, noting that the male and female genitalia indicated it was not closely related to *Lygus*. All species of *Taylorilygus* are confined to the Afro-tropical region, except *T. pallidulus* (Blanchard), a polyphagous "cosmopolitan" species. Taylor (1947) described most of the species, indicated host plants, and provided an identification key. Kelton (1955a) considered *Taylorilygus* most closely related to the Neotropical genus *Dagbertus* Distant. These two genera are similar externally, but the genital structures and the very short third antennal segment of *Dagbertus* will distinguish them (Kelton, 1955a; Slater and Baranowski, 1978). Carvalho (1983) reviewed *Dagbertus*, providing descriptions of 12 new species, a checklist of the species, and a key to help separate them.

PROBLEMS INVOLVING THE TAXONOMY OF NORTH AMERICAN *LYGUS*

Despite efforts to clarify the species level taxonomy of *Lygus* and related genera, it is difficult to positively identify many commonly encountered specimens. This hinders the development of species-specific programs involving, for example, biological control agents. The taxonomic difficulty stems chiefly from the inability to determine species in *Lygus* accurately and from their variability throughout their ranges. Macromorphological systematic techniques may have been used to their limit. Micromorphological studies, including the use of the scanning electron microscope (SEM), are called for and, in fact, have produced some promising results on a limited basis (J.D. Lattin and V. Razafimahatratra, unpub.).

Contemporary biochemical techniques should be used, such as those of Sluss et al. (1982), together with crossbreeding investigations (Graham, 1982). The development of an artificial diet for *Lygus* makes easier the maintenance of laboratory cultures for study (Debolt, 1982). Sex pheromones have been detected in several species of Miridae, including *Lygus*, and should be investigated further (Boivin and Stewart, 1982). Adequate samples, well documented and appropriately preserved, should be collected over a wide area. Such samples would also assist in studies involving geographic variation. Because considerable seasonal variation in the adults is known to occur (Kelton, 1975), samples should be taken during more than one season.

It is not now possible to identify nymphs to species accurately. Well-preserved nymphs associated with adults should be collected for study. Some mirid nymphs can be identified to species in other genera, but comparatively little work has been done on nymphal taxonomy (see previous section on nymphs). It also is possible that useful taxonomic characters might be found on the eggs of *Lygus*. The SEM would be an essential investigative tool for such work. All the available information should be assembled and analyzed utilizing contemporary systematic methods.

Once a more solid systematic base has been established, it may be possible to clarify other puzzling questions, for example, the broad geographical ranges of many species that often overlap those of several others. Is this the case, or are we unable to recognize other taxa adequately, or are they the same species? It is clear that there is seasonal variation and, most likely, geographical variation. We are not yet able to cope fully with these

variables. Carefully conducted life history studies, with voucher specimens, are needed to clarify these problems.

The available host plant data present a bewildering array of plant taxa with few indications of any ordered associations. Clear distinction should be made between resting, feeding, and hosts supporting nymphs such as was done by Fye (1980) or Snodgrass et al. (1984), who indicate when adults or nymphs or both were collected. Damage can occur on crops where *Lygus* bugs do not breed and oviposit, especially because adults readily migrate to and feed on plants where nymphs do not occur.

Careful attention should be given to the phenology of the host plant and the occurrence of *Lygus* on the plant. Almost certainly some of the apparent confusion over host association is due to host plant shifts in different parts of the bug's range. Fox and Morrow (1981) pointed out that a species may be a generalist throughout its range but a specialist locally. Species of the genus *Lygus* would seem to be excellent subjects for such an analysis once the taxonomy is better known. A species such as *Lygus lineolaris*, already well defined but very widespread and apparently rather polyphagous, would be a fine candidate for such a study.

And finally, if a rational approach is to be taken in seeking possible biological control agents, particularly in other parts of the world, it is essential to know just where the genus *Lygus* fits in the overall phylogeny of the Miridae. A more indepth comparison of the mirine genera is needed using contemporary phylogenetic analysis. When we know more about the near relatives of *Lygus* and where they occur, searches for more effective biological control agents are likely to be more successful. Although there is no guarantee that seeking such agents from near relatives will produce successful results, it does put such efforts on a more ordered basis (Condit and Cate, 1982).

RECOMMENDATIONS FOR FUTURE WORK

(A) Short term
- (1) Adults
  - Micromorphological studies
  - Biochemical studies, including allozymes and pheromones
  - Hybridization studies
  - Adequately vouchered and preserved samples from broad geographical areas
- (2) Nymphs and eggs
  - Procurement of associated samples
  - Micromorphological studies
- (3) General
  - Accurate, vouchered host data over broad geographical area
  - Thorough life history studies, including hosts, phenology, and population dynamics
  - Studies of associated predators and parasites

(B) Long term
- Analysis and synthesis of short-term information
- Systematic revision of the genus *Lygus*
- Phylogenetic studies of *Lygus* spp. and near relatives
- Host plant resistance studies

SOME FINAL QUESTIONS

A review of this kind frequently raises more questions than it answers. Our knowledge is so rudimentary in some areas as to make progress difficult. Nevertheless, some intriguing questions may be raised, the answers to some of which may eventually come from work on *Lygus*.

--What makes the native species of *Lygus* move so readily to introduced plants, including crop plants?

--Although some *Lygus* feed on various legumes, why have they not transferred to soybeans, even though a large number of other insects have done so, including *Lygocoris* (*Apolygus*) *lucorum* (Meyer-Dür) (Lattin and Hall, 1983)?

--How is it possible to explain the apparent great range of acceptable

host plants for some Lygus species? There are species included in the genus that appear to be host-plant specific and may be typical k-selected species.

- --What adaptive features of Lygus spp. enable them to occupy (apparently) such a wide geographic range? Can these attributes be identified and included in predictive models on pest potential?
- --Some species of Lygus are sometimes found together on crops. What are the consequences of this apparent interspecific competition?
- --Are there special attributes of the pest species of Lygus that allow them to adjust to unstable, disturbed environments and thereby enable them to become pests in the first place? Are they less of a problem in no-tillage systems?
- --What can be learned by analyzing the nature of the predator-parasite complex associated with each species of Lygus, including those that are not pests?
- --Why haven't some Lygus species been introduced into other countries accidentally?
- --Although many European insects have been introduced into North America, including a large number of Miridae, where are the common European species of Lygus? Several European species of Lygus are regularly intercepted at U.S. ports by APHIS Plant Pest Quarantine personnel (pers. observ., T.J. Henry). All earlier reports of European species of Lygus in North America apparently are based on misidentifications. It is possible that some of these species are present in our fauna but have gone undetected. If not, why haven't these species become established?

Quite clearly, although much is known about Lygus bugs and many authors have contributed to this knowledge, there is much to learn.

ACKNOWLEDGMENTS

We thank V.D. Razafimahatratra, National University, Malagasy Republic, Madagascar, for sharing his views on some of the problems in the genus Lygus. Many useful suggestions have been made by R.C. Froeschner, Department of Entomology, National Museum of Natural History (NMNH), Washington, D.C.; R.W. Hodges, Systematic Entomology Laboratory, Agricultural Research Service, USDA, c/o NMNH; and A.G. Wheeler, Jr., Bureau of Plant Industry, Pennsylvania Department of Agriculture, Harrisburg, Pa.

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APPENDIX

The following classifications of Lygus are from Knight (1917) to the present:

(1) Knight (1917) treated only North American taxa:
Genus Lygus Hahn
Group I (pratensis group; considered Lygus lineolaris (Palisot) a junior synonym of Lygus pratensis (Linneaus))
Group II (campestris group)
campestris Linneaus (subg. Orthops Fieber)
distinctus Knight (now in Knightomiris Kelton)
rubicundus Fallén (subg. Agnocoris Reuter)
sallei Stål (now in Proba Distant)
Group III approximatus Stål (now in Pinalitus Kelton)
Group IV
fasciatus Reuter (now in Dagbertus Distant)
olivaceus Reuter (now in Dagbertus)
Group V
apicalis Fieber (now in Taylorilygus Leston)
Group VI (communis group; subg. Neolygus Knight)
contains 39 species in North America

(2) China (1943) treated British genera:
Genus Liocoris Fieber
(type-species tripustulatus (Fabricius))
Genus Lygus
Subgenus Agnocoris
(type-species rubicundus)
Subgenus Apolygus China
(type-species limbatus Fallén)
Subgenus Lygus
(type-species pabulinus Linnaeus)
Subgenus Orthops
(type-species kalmii Linnaeus)

(3) Wagner (1949) treated Palaearctic genera:
Genus Lygus
Subgenus Agnocoris
(type-species rubicundus)
Subgenus Apolygus
(type-species limbatus)
Subgenus Exolygus Wagner
(type-species pratensis)
Subgenus Lygus
(type-species pabulinus)
Subgenus Orthops
(type-species kalmii)

(4) Leston (1952) gave a world review of Lygus and subgenera:
Genus Lygus
Subgenus Agnocoris
(type-species rubicundus)
Subgenus Exolygus
(type-species pratensis)
Subgenus Lygus
(type-species pabulinus)
Subgenus Neolygus
(type-species communis Knight)
Subgenus Apolygus, a junior synonym (type-species limbatus)
Subgenus Orthops
(type-species kalmii)
Subgenus Taylorilygus Leston
(type-species simonyi Reuter)

(5) Kelton (1955a) treated Lygus and associated genera:
Genus Agnocoris
(type-species rubicundus)
Genus Cyphodema Fieber
(type-species instabilis Lucas)
Genus Dagbertus
(type-species darwini Butler)
Genus Liocoris
(type-species tripustulatus)
Genus Exolygus, a junior synonym
(type-species pratensis)
Genus Lygus
(type-species pabulinus)
Subgenus Apolygus
(type-species limbatus)
Subgenus Lygus
(type-species pabulinus)
Subgenus Neolygus
(type-species communis)
Subgenus Stechus Distant
(type-species libertus Distant)
Genus Orthops Fieber
(type-species kalmii)
Genus Pinalitus
(type-species approximatus)
(group III of Knight (1917))
Genus Proba

(type-species gracilis Distant)
(sallei group of Knight (1917))
Genus Sabactus Distant
(type-species institutus Distant)
Genus Salignus
(type-species distinguendus Reuter)
(in group I of Knight (1917))
Genus Taylorilygus
(type-species simonyi)

(6) Current scheme, ruling of International Commission of Zoological Nomenclature (1963); other generic concepts (not listed) follow Kelton (1955a, 1974):
Genus Liocoris
(a subjective junior synonym of Lygus; currently considered a distinct genus)
Genus Lygocoris
(type-species pabulinus)
Subgenus Apolygus
(type-species limbatus)
Subgenus Lygocoris
(type-species pabulinus)
Subgenus Neolygus
(type-species communis)
Subgenus Stechus
(type-species libertus)
Genus Lygus
(type-species pratensis)
Genus Exolygus (same type-species; an objective junior synonym of Lygus)

EUPHORINE PARASITES OF *LYGUS* AND *ADELPHOCORIS* (HYMENOPTERA: BRACONIDAE AND HETEROPTERA: MIRIDAE)

By Conrad C. Loan and Scott R. Shaw[1]

Lygus Hahn is a genus with 34 North American and 7 European species. Adelphocoris Reuter is a European genus with three species, of which two are introduced economic pests in North America. Insects in both genera are attacked in their nymphal stages by parasites in the tribe Euphorini, family Braconidae.

Peristenus Foerster and Leiophron Nees are allied to four other genera in the Euphorini (Loan, 1983), which are each host specific for a family of Heteroptera or Psocoptera. Reared material is rare and the parasites are not well known, although their plant bug hosts are the commonest of the Heteroptera. For example, in the British Isles, six species of Peristenus and two of Leiophron have been associated with hosts (Brindley, 1939; Richards, 1967; Waloff, 1967; Loan and Bilewicz-Pawińska, 1973). These hosts are from a plant bug fauna of 193 species, of which 26 percent are recorded as hosts of euphorine larvae (Southwood and Leston, 1959). In North America, hosts are known for 14 species of Peristenus and 4 of Leiophron, and unidentified euphorine larvae occur in 24 additional host species (Loan, 1980).

BIOLOGY

The euphorines attacking plant bugs emerge from overwintered cocoons, and, having ripe oocytes, they immediately attack early-instar nymphs. A single parasite larva develops in the host and usually emerges from the fifth-instar nymph. Infrequently, development of the first instar is arrested until the host is an adult (Leston, 1961; Loan, 1965, 1966). For most reported associations, the adult parasite diapauses in its cocoon. Spring emergence is nearly synchronous with the hatching of host nymphs from overwintered eggs (Waloff, 1967; Bilewicz-Pawińska, 1978). Nondiapausing species occur in Kenya (Taylor, 1945) and bivoltine ones in Poland (Bilewicz-Pawińska, 1977).

The relatively few host-associated species have a restricted host range. Some are monophagous, but others attack a small number of species on the same plant or type of plant growth (Loan, 1980). It is clear that diapause of plant bug parasites is an important component of specificity, because it prevents temporal separation from the host after overwintering.

Peristenus and Leiophron are most easily detected by dissection of nymphs and adults, because the parasite cocoon is hard to find in the soil and parasite adults are difficult to collect; they fly for only a short time. Rearing field-collected material in the laboratory is more successful if one obtains late-instar nymphs to minimize the duration of host feeding and parasite development.

TAXONOMY

Taxonomic reviews of Peristenus and Leiophron are available for species from North America (Muesebeck, 1936; Loan, 1974b) and from Europe (Richards, 1967; Loan and Bilewicz-Pawińska, 1973; Loan, 1974a). Nixon (1946) reviewed the African species reared by Taylor (1945). New name combinations were provided (Loan, 1974b) because of the separation of Peristenus from Leiophron (Loan and Bilewicz-Pawińska, 1973).

Larvae have specific characters of setae and head sclerites (Waloff, 1967; Bilewicz-Pawińska, 1974), but their taxonomy has not progressed enough to permit identifications to either genus or species.

Species of Leiophron have diverse structural characters and thus are easier to recognize than species of Peristenus, which are very similar and identified chiefly by host association or seasonal

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occurrence. Among current taxonomic problems is the species complex of P. pallipes (Curtis), P. pseudopallipes (Loan), and P. adelphocoridis Loan. Studies should assess the validity of P. adelphocoridis and also the status of the North American P. pallipes (Loan, 1974b). Although P. pseudopallipes is nearly inseparable morphologically from P. pallipes, its temporal separation is evidence of species isolation (Loan, 1970).

KEY TO EUROPEAN AND NORTH AMERICAN EUPHORINE PARASITES OF *LYGUS* AND *ADELPHOCORIS*

1. Ventral margins of abdominal tergite 1 widely separated from each other (fig. 1, A). Mesonotum with notauli absent or at least effaced posteriorly (fig. 1, C). Forewing veins effaced apically (fig. 1, E), first intercubitus and recurrent vein absent---------------------Genus Leiophron Nees 2

   Ventral margins of abdominal tergite 1 meeting basally (fig. 1, B). Mesonotum with notauli foveate and always distinct posteriorly (figs. 1, D; 2, E-F). Forewing veins complete apically (figs. 1, F; 2, D), first intercubitus and recurrent vein present---------------Genus Peristenus Foerster 3

2. Occipital carina effaced dorsally (fig. 2, A). Eye not as wide as temple (fig. 2, B). Distance between eye and base of mandible (malar space) approximately as long as basal width of mandible (fig. 2, C). Propodeum usually yellow, not notably darker than thorax------------Leiophron uniformis (Gahan)

   Occipital carina weakly present dorsally. Eye as wide or wider than temple. Malar space 2.0 times as long as basal width of mandible. Propodeum brown, notably darker than thorax----------------Leiophron lygivora Loan

3. Mesonotum smooth and polished anteriorly, not punctate (fig. 2, E). Radial cell on wing margin about 0.3 times as long as stigma (fig. 2, D). Antennal segments 18-20 (♀), 19-21 (♂)--------------------------------Peristenus stygicus Loan

   Mesonotum punctate anteriorly (figs. 1, D; 2, F). Radial cell at least 0.5 times as long as stigma. Antennal segments 19-25 (♀), 22-28 (♂)--------------------------- 4

4. Bicolored, or black with face distinctly paler than genae, frons, and vertex-------------- 5

   Black without pale face or reddish head or thorax - pallipes species group[1/]---------------- 6

5. Bicolored, head behind eye (♀) and face, genae, vertex, and mesonotum (♂) light reddish. Antennal segments 22-25 (♀), 22-24 (♂)-----------------------Peristenus rubricollis (Thomson)

   Black, dorsal eye orbit black or narrowly reddish (♀), face paler than genae or vertex. Antennal segments 18-20 (♀), 18-21 (♂)------------------------------Peristenus digoneutis Loan

1/ A complex group of sibling species, which needs further taxonomic work. The species are morphologically similar and most easily identified if host and date of emergence are known.

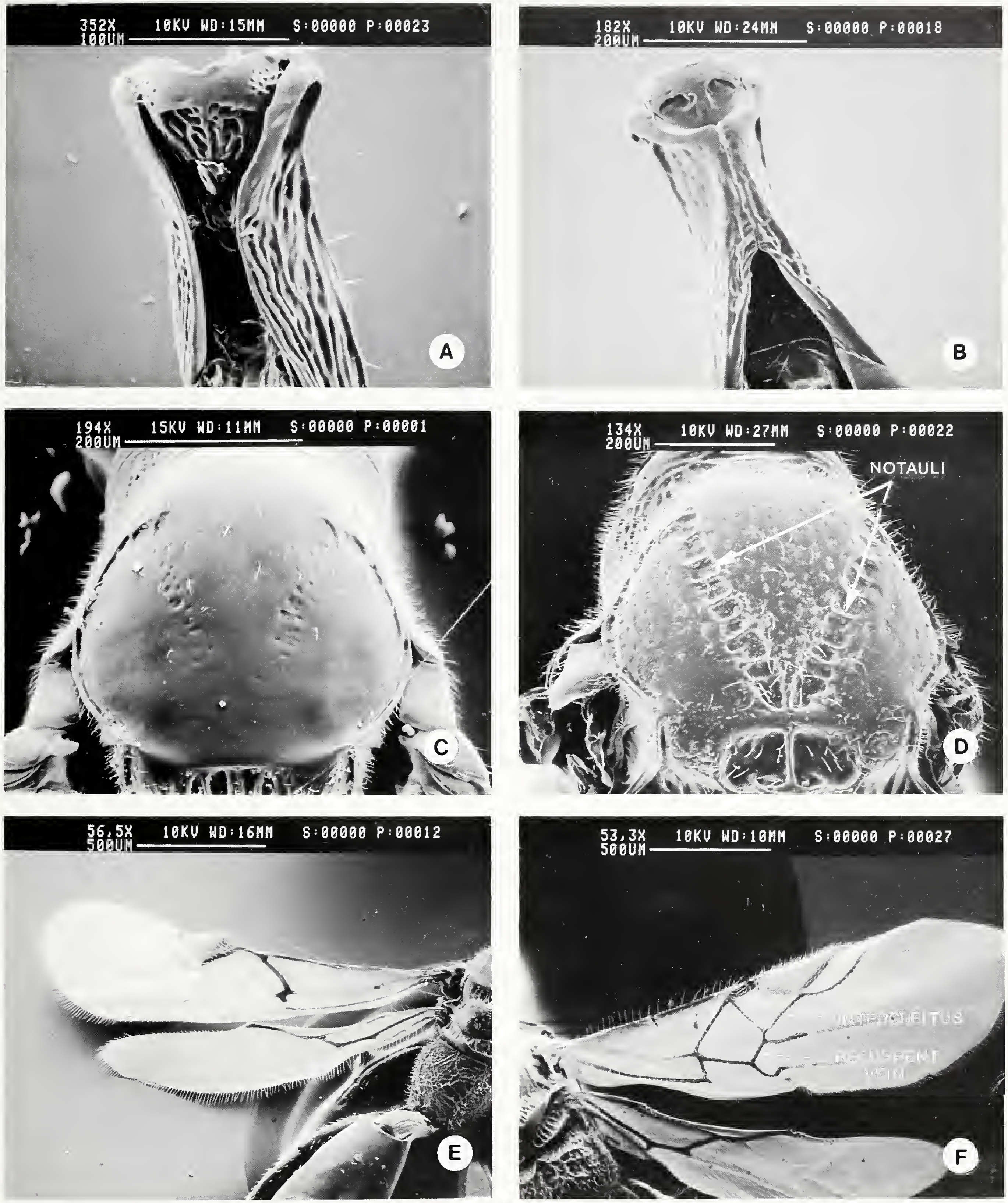

Figure 1
Petiole, ventral view: A, Leiophron uniformis (Gahan); B, Peristenus digoneutis Loan. Mesonotum, dorsal view: C, L. uniformis; D, P. pallipes (Curtis). Wings: E, L. uniformis; F, P. stygicus Loan.

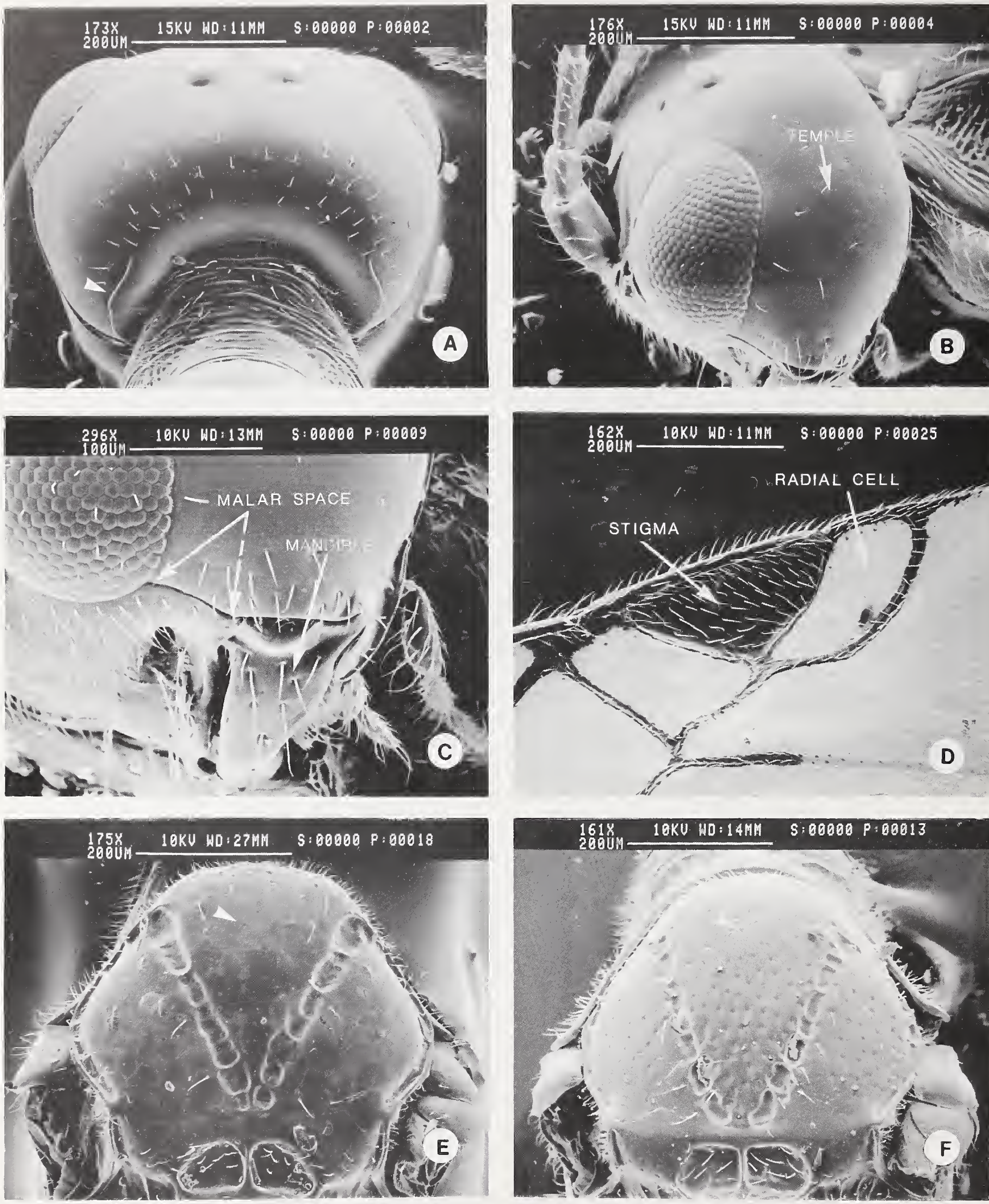

Figure 2
Head, Leiophron uniformis (Gahan): A, Dorsal view showing effaced occipital carina; B, lateral view showing eye/temple ratio; C, lateral view showing malar space/mandible width ratio. Forewing: D, Peristenus stygicus Loan. Mesonotum, dorsal view: E, P. stygicus; F, P. digoneutis Loan.

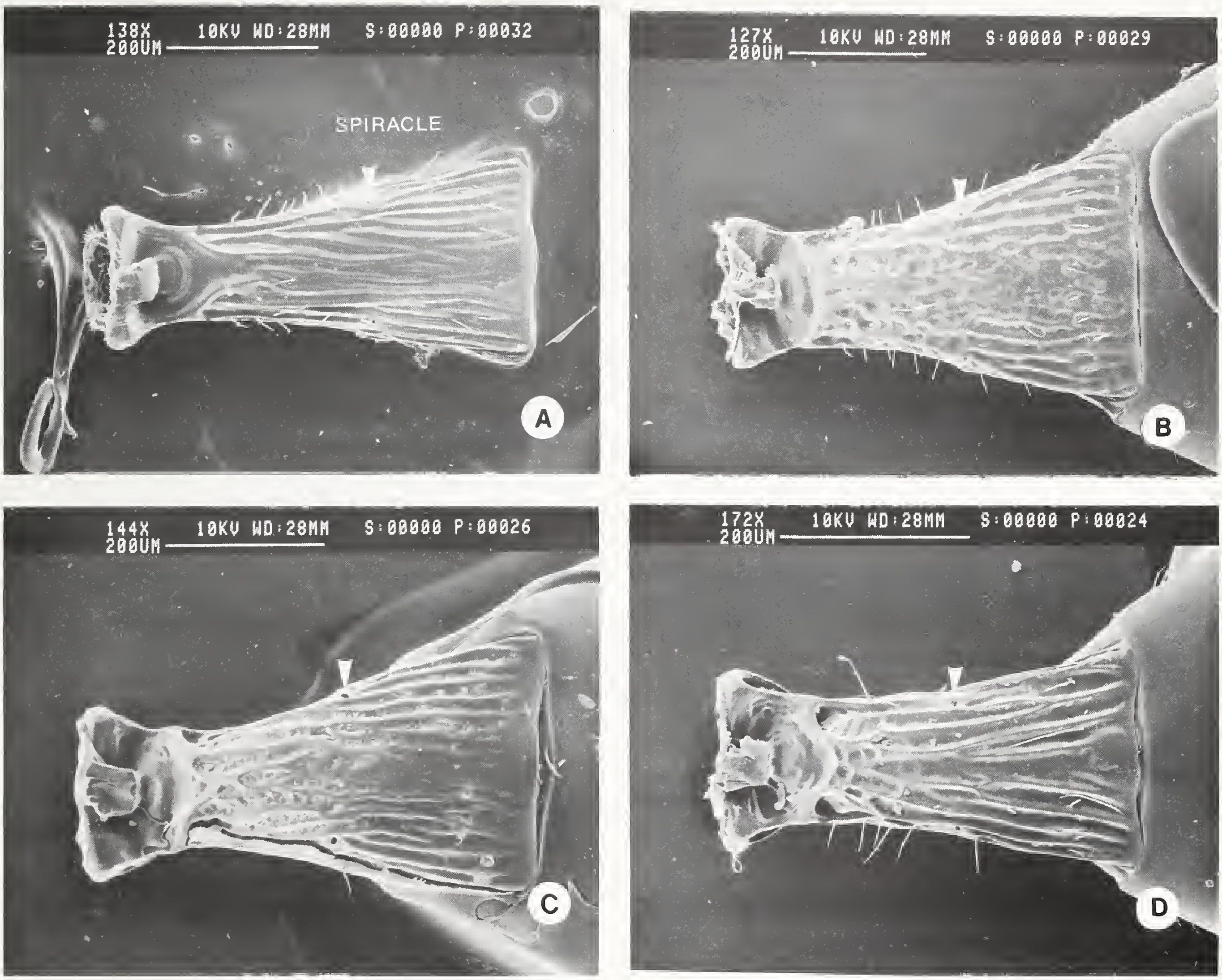

Figure 3
Petiole, dorsal view: A, Peristenus adelphocoridis Loan; B, P. pseudopallipes (Loan); C and D, P. pallipes (Curtis).

6. Spiracles of abdominal tergite 1 distinctly behind middle of tergite (fig. 3, A), tergite before spiracle 1.6 times as long as tergite behind spiracle. Parasites of Adelphocoris --------------------- Peristenus adelphocoridis Loan

Spiracles of abdominal tergite 1 closer to middle of tergite (figs. 3, B-D), tergite before spiracle 1.1-1.3 times as long as tergite behind spiracle. Parasites of Lygus or Adelphocoris------------------ 7

7. Antennal segments (♀), 21-25, usually 22-23. In North America, adults occurring in spring and early summer (prior to mid-July). Abdominal tergite 1 with distinct costae (figs. 3, C-D)---------------------- Peristenus pallipes (Curtis)

Antennal segments (♀), 19-24, usually 21-22. In North America, adults occurring in late summer to fall (after mid-July). Abdominal tergite 1 mostly without distinct costae (fig. 3, B)------------- Peristenus pseudopallipes (Loan)

ACKNOWLEDGMENTS

We thank W.R.M. Mason, Biosystematics Research Centre, Agriculture Canada, Ottawa, and P.M. Marsh, Systematic Entomology Laboratory, U.S. Department of Agriculture, Washington, D.C., for their helpful suggestions.

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FOREIGN EXPLORATION FOR NATURAL ENEMIES OF *LYGUS* AND *ADELPHOCORIS* PLANT BUGS

By Robert C. Hedlund[1/]

Exploration for natural enemies of Lygus and Adelphocoris (Hemiptera: Miridae) plant bugs has been undertaken in Europe, Africa, and Asia since the 1960's. Earlier studies (Taylor, 1945; Nixon, 1946) were completed in Uganda. Most exploration work outside of North America has been funded by United States and Canada. The major efforts have been undertaken by Bilewicz-Pawińska (1969, 1974a, 1974b, 1975, 1977) in Poland; the Commonwealth Institute of Biological Control (CIBC, 1981) in Pakistan, India, Iran, Turkey, and Indonesia; the European Parasite Laboratory (EPL), USDA (Drea et al., 1973; Hedlund and Coutinot, 1984) in France, Austria, Germany, Switzerland, Turkey, Spain, Italy, Greece, and Hungary; the CIBC, Delémont Station (CIBC, annual reports, Delémont Station) in Austria, Switzerland, Germany, and France; and A.A. Negm and M.F. Abou Ghadir (annual reports, PL-480 project FG-EG-193) in Egypt. Survey trips to the Republic of South Africa and Kenya have recently been completed by M.F. Schuster (see p. 13).

Evaluating the results of these studies is difficult because much of the literature is in annual reports rather than in scientific publications, and adequate details of the methods are sometimes lacking. Also, the nomenclature of both the hosts and their natural enemies is changing or is imprecise (Henry and Lattin, see p. 54; Loan and Shaw, see p. 69).

A list of natural enemies of some mirid bugs around the world has been published by Clancy and Pierce (1966) and was later updated by CIBC (1979).

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DISCUSSION

Poland Project

The work in Poland has been well documented by the chief investigator, Teresa Bilewicz-Pawińska, in several publications (1969, 1974a, 1974b, 1975, 1977). In alfalfa she found three species of Peristenus Foerster (Braconidae, Euphorinae) attacking Lygus nymphs. They were P. rubricollis (Thomson), P. digoneutis Loan, and P. stygicus Loan; P. digoneutis was the most common. Parasitism ranged from 1 to 25 percent and peaked at about the same time as the host population.

Adelphocoris lineolatus (Goeze) was reported to be attacked by P. rubricollis and P. pallipes (Curtis), and parasitism did not exceed 10 percent. Parasitism of adult A. lineolatus by Peristenus was extremely rare, whereas parasitism of adult Lygus rugulipennis Poppius was common. For both host species, the percent parasitism was calculated for the total sample, which included both nymphs and adults.

In an earlier study (1969) in rye, she separated the parasitism of nymphs and adults. As would be expected, the percentage of parasitized nymphs was generally much higher than that of parasitized adults. This is because the only euphorine parasites found in adults were those that did not complete their development in the nymphs as is usual. In studies by EPL (Hedlund, unpub.), emergence of euphorine parasites from adults, although recorded, has been extremely rare.

Several shipments of these four Peristenus species from Poland were sent to the United States. Unfortunately no establishments resulted, but a great deal of knowledge about the ecology and biology of both the hosts and their parasites was acquired.

Pakistan Project

This summary is based on the annual and final reports of a PL-480 project (PK-ARS-91) (CIBC, 1981). This study by

the Pakistan Station of CIBC was done from 1975 to 1978. The original proposal called for work in Afghanistan and China, as well as Pakistan, Iran, and Turkey, but the first two countries were later omitted and the work was done in India and Indonesia.

In Pakistan, parasites were extremely rare. Some mymarid egg parasites were found on both *Lygus* and *Adelphocoris*. No parasites were recorded from the rearing or dissection of over 160,000 nymphs and adults during the 3-year study, despite collections in more than 30 localities, in 8 different climatic zones, and throughout the year. It is interesting to note that *Lygus* spp. were not found in the cotton-growing areas of Pakistan. Twenty-seven species of mirids were recorded for the first time from Pakistan. The collections included more than 42,000 nymphs of *Lygus gemellatus* (Herrich-Schaeffer), 5,000 nymphs of *Taylorilygus pallidulus* (Blanchard), nearly 13,000 nymphs of *Calocoris* spp., and 5,000 nymphs of *Adelphocoris lineolatus*. These numbers seem adequate to have detected the presence of nymphal parasites if they occurred. Six species of predators were found in association with *Lygus*. The most common were *Nabis ferus* L., a well-known predator of *Lygus*, and a *Chrysopa* sp. (Chrysopidae). The other four were *Tropiconabis capsiformis* (Germar) (Nabidae), *Geocoris tricolor* F., *Piocoris* sp. (Lygaeidae), and *Orius* sp. (Anthocoridae).

One collecting trip of 3 to 4 months was made to Bangalore, India. Although 12 species of mirids were recorded, only 376 nymphs from 19 locations were collected. No *Lygus* or *Adelphocoris* species were found. Of the nymphs, 146 were *Taylorilygus pallidulus* collected on *Erigeron bonariensis* L. in 5 localities. This sample is not adequate to draw any conclusions about the presence of mirid parasites in India.

The survey in Indonesia was carried out around Bogor, West Java, between August and December 1976. Two species of mymarid egg parasites were recovered from what the investigators presumed were eggs of *Lygus*. One of the parasites was identified as *Erythmelus helopeltidis* Gahan, and it attacked up to 55 percent of the eggs deposited in *Amaranthus dubius* Mart. ex Thell., a weed. Nymphs of a probable *Lygus* species are mentioned as being more abundant in one field than in another, but the report does not indicate how many were collected, examined, or reared to detect the presence of parasites. Hundreds of *Nesidiocoris tenuis* (Reuter) specimens from tomato were reared, but they produced no parasites.

Iran and Turkey were surveyed in a 3-month tour during May-July 1977. In Iran, over 25,000 adults and nymphs of 19 species of mirids were collected. A total of 1,541 nymphs and 10,151 adults of *Lygus gemellatus*, *L. rugulipennis*, and *L. pratensis* (L.) were collected from about a dozen sites and several different host plants. Also, 242 nymphs of *Adelphocoris lineolatus* were collected. No egg or nymphal parasites were recovered in Iran.

In Turkey, over 14,500 adults and nymphs of 35 species of mirids were collected. Although no parasites were recorded, the predator *Nabis ferus* was fairly abundant, and *Geocoris* and *Chrysopa* species were seen occasionally. Nearly 2,000 nymphs of the same 3 species of *Lygus* as reported from Iran were recovered along with almost 2,000 nymphs of *A. lineolatus*.

Egypt Project

The study in Egypt included cataloging the mirid fauna and its parasites as completely as possible. Although *Lygus* species had previously been reported from Egypt (Hoberlandt, 1953; Priesner and Alfieri, 1953; Linnavuori, 1964), none have been recovered in the current survey, which began in 1978 and is now in its eighth year. No parasites of any nymphal mirids have been recovered. During 1978-79, 128 specimens of *Taylorilygus pallidulus* were recovered and held for parasite emergence. In 1980, 151 *T. pallidulus* specimens were

collected. The annual reports on which this summary is based do not indicate what percentage were nymphs. Predators in the genera *Orius*, *Chrysopa*, *Coccinella*, *Scymnus*, *Geocoris*, *Nabis*, and *Coranus* were recovered in association with the mirids. In the combined report for 1981 and 1982, nymphs were collected from March to June 1981, and no nymphal parasites have yet been recovered. A scelionid egg parasite, *Telenomus* sp., was collected. In the 1983-84 report, no nymphal parasites were recovered by rearing or by dissecting nymphs.

In the remainder of Africa, this subject was studied in Uganda in the 1940's (Taylor, 1945) and in Kenya and South Africa at the present time. Taylor found *Peristenus praetor* (Nixon) and *P. nigricarpus* (Szepligeti) attacking up to 98 percent of *Taylorilygus vosseleri* (Poppius) on cotton.

Explorations in the Republic of South Africa during May 1981 resulted in the collection and shipment of 900 nymphs, of which 40-50 percent were parasitized (Schuster, see p. 16). Unfortunately the delayed shipment resulted in near total mortality. A second survey in January 1982 resulted in the receipt of 665 cocoons from the black wattle mirid *Lygidolon laevigatum* Reuter. From them, 167 parasites emerged, comprised of *Mesochorus melanothorax* Wilkinson, a hyperparasite, and *P. praetor* and *P. nigricarpus*. F_1 generations of both *Peristenus* species were obtained from *Lygus lineolaris* (Palisot) in the laboratory. No F_2 of *P. nigricarpus* resulted, and only three F_2 adults (no F_3) of *P. praetor* were obtained (G.L. Snodgrass, pers. commun.).

Schuster (see p. 16) went to Kenya in October 1983. Nymphs of *Taylorilygus* spp. were collected from grain sorghum and *Lantana camara* L. The emerging *Peristenus* specimens were provided nymphs of *T. pallidulus*, *Lygus hesperus* Knight, and *L. lineolaris* in quarantine at Stoneville, Miss., but cultures could not be maintained beyond the F_2 generation (G.L. Snodgrass, pers. commun.).

EPL Project

Exploration for natural enemies of mirids began in August 1962 at EPL. Collections were made throughout France, in the Ura region of Switzerland, and in West Germany. Few nymphs were collected, but parasitism ranged up to 50 percent in some *Lygus* collections. These parasites were later identified as *Euphorus pallipes* (Curtis). No parasites were recovered from any stage of *Adelphocoris*, although this pest was far more abundant than *Lygus*. In a second survey in April and May 1963, 9,000 nymphs were collected in West Germany and 3,000 in France. These produced 56 cocoons. Laboratory culture increased this number to 110 progeny, which were sent to California, where there was no adult emergence. In 1964, surveys were made in the Paris area during August and September, but only 40 parasite cocoons were formed, although 140 parasite larvae emerged from 3,243 nymphs. Work on this project then ceased until 1970, when a September survey near Chartres, France, resulted in 27 cocoons (*Leiophron* spp.) from 600 *Lygus* nymphs.

In 1971, 300 nymphs of *Polymerus unifasciatus* (F.) collected on asparagus near Izmir, Turkey, produced 40 *Peristenus stygicus* cocoons (Drea et al., 1973). Sent to the United States and cultured, they resulted in the only recorded establishment, although temporary, of an exotic parasite of mirids (van Steenwyk and Stern, 1977). Additional surveys in France in 1971 revealed the presence of three species of *Peristenus* (originally called *Leiophron*). These were *P. stygicus*, *P. digoneutis*, and *P. rubricollis*. In 1976, a fourth species, *P. adelphocoridis* Loan, was found attacking *Adelphocoris lineolatus* (Loan, 1979). A total of 750 cocoons, including the 40 from Turkey, were sent to the United States in 1971.

In 1972, collections were made in eastern France and Germany. A total of 2,190 nymphs yielded 270 *Peristenus* parasites.

Table 1 is a summary of the number of *Peristenus* spp. sent to the United States by EPL during 1973-83. This was a period when a rather consistent effort was made

to recover natural enemies of these mirids. The majority of the collections were made in France and Austria. A grand total of 14,363 Peristenus spp. were shipped, most of which were released directly in the field on emergence, but some were cultured (Debolt, see p. 83) and the progeny released.

This summary refers only to Peristenus nymphal parasites, and, in fact, the major effort was to collect them. A mymarid egg parasite, Erythmelus sp. near goochi Enock (determ. by G. Gordh), was found, but efforts to trap large numbers by placing egg-infested plant material in the field did not succeed. A tachinid, Alophora obesa (F.), emerged from adults collected in Austria, and 21 puparia and adults were shipped in 1980. These were released in a field cage in Delaware. In addition, in 1977, three shipments of two species of mermithid nematodes were made. One was tentatively identified by W.R. Nickle as Agamermis near decaudata. A nematode was earlier reported by Bilewicz-Pawińska and Kamionek (1973) on Lygus rugulipennis. No observations have been made by EPL on the predator complex of the pest mirids.

CIBC, Delémont Project

This project has been funded by Canada and very closely resembles that of EPL. In some years, USDA contributed financially to the work, and personnel from both laboratories worked together in the field. Collections made in various countries of Europe have resulted in the recovery of the same parasite species as those reported in the EPL project. There has been no establishment of an exotic species in Canada. Current efforts are concentrated on obtaining large numbers of Peristenus adelphocoridis, because its host, Adelphocoris lineolatus, occurs in

Table 1
Number of specimens and source country of Peristenus spp. sent to United States by European Parasite Laboratory, 1973-83

		Peristenus--			
Year	Country	digoneutis	stygicus	rubricollis	adelphocoridis
1973	France	152	---	---	
1974	Poland	---	---	85	
	France	26	60	9	
1975	France	73	---	30	
1976	France	340	180	124	
1977	Austria	120	[1]275	---	
	France	631	[1]763	[1]232	
1978	Austria[2]	1,036	41	59	
	France	2,273	[1]1,388	[1]181	
1979	Austria	7	---	---	
	France	1,562	9	---	
1980	Spain	---	35	---	
	Austria	384	41	76	
	France	130	---	---	
1981	Austria	1,261	26	24	
	France	1,201	5	4	
1982	Spain	---	88	---	
	France	139	---	---	67
1983	Hungary	56	98	---	
	Greece	---	30	---	
	Spain	---	65	---	
	France	568	76	17	316
Total		9,959	3,180	841	383

[1] Some material laboratory reared.

[2] Austrian collections done in cooperation with CIBC, Delémont.

both North America and Europe. This fact implies increased probability of establishment of its European parasites in North America. More specific results of this project are contained in informal annual reports and thus cannot be cited or summarized here.

Future Exploration

A large part of the world remains to be explored for natural enemies of Miridae. Central and southern Europe, a small section of Asia, and four countries on the African continent have been the only areas surveyed for natural enemies for importation into North America. Not all these surveys were adequate owing to limitations of time, personnel, and funding.

Ideally, the first new areas to be surveyed should be where adequate populations of mirids, closely related or identical to pest species of North America, are known to be present. The ecology and biology of these hosts, as well as those of the natural enemies, should be thoroughly studied. The natural enemies most likely to succeed in becoming established should then be tested against the proposed target hosts to determine host suitability. Host range, predaceous habits, and any phytophagous tendencies should also be evaluated and compared to potential benefits. When results of these studies are favorable, mass collection and release should begin and continue for 3-4 years to attempt establishment of the natural enemy. This should then, of course, be followed by a thorough evaluation of the effectiveness of the established species. In reality, however, information on occurrence of closely related mirids does not usually exist, although the Pakistan and Egypt projects have provided this information in the areas surveyed. Funding and political considerations often prevent long-term studies in foreign countries, and lack of culture techniques, especially for predators and nematodes, precludes host range and other tests. All these obstacles can be overcome with sufficient effort and time, but it appears unlikely that such a commitment will be made in the near future.

There are possibilities for work to be done under cooperative agreements, such as the Binational Agricultural Research and Development Fund agreement with Israel. Special Foreign Currencies still exist in some countries, such as India, Pakistan, Poland, and Yugoslavia, and projects using these funds can be initiated through the Office of International Cooperation and Development, an agency of the USDA. With additional personnel, the Asian Parasite Laboratory, USDA, could undertake a long-term study in Korea, a country very similar in climate to large areas of the United States and southern Canada. The exchange programs with the People's Republic of China and the Union of Soviet Socialist Republics offer possibilities for short-term investigations, but permission to export the natural enemies needs to be clearly specified at the outset.

Almost nothing is known about mirids or their enemy complex in South America or in eastern Africa. It is possible that effective and potentially useful natural enemies exist in these areas.

CONCLUSIONS

Surveys in Europe, South Central Asia, and some African countries during the 1960's and 1970's have resulted in the discovery of several natural enemies of mirids. Although predators and egg and adult parasites have been observed, they have not been studied. Importations into North America have concentrated on hymenopterous parasites of the nymphs. Apparently none of these have become established though they often attack the proposed hosts in the laboratory and are sometimes found in the field for short periods after release. Most of the world's agricultural areas, sometimes including entire continents, have received no survey effort. Although various areas could be explored to some extent, there is a need for a large and

long-term commitment by North American agricultural research organizations to investigate fully the potential of exotic natural enemies of mirids for controlling the pest species of North America.

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AUGMENTATION: REARING, RELEASE, AND EVALUATION OF PLANT BUG PARASITES

By Jack W. Debolt[1]

Augmentation of natural enemies can be defined as any action used to increase populations or effectiveness of the beneficial organisms. As such it can include environmental manipulations as well as periodic releases of selected natural enemies. This report deals with the latter factor, specifically the potential for using properly timed periodic releases of selected parasites as a component in Lygus spp. management programs.

Lygus lineolaris (Palisot) is the major pest species in the Eastern and Southern United States and Canada, whereas Lygus hesperus Knight takes over this role in the Southwestern and Western United States. Of the six North American hymenopterous parasites of Lygus spp. listed by Krombein et al. (1979), two nymphal parasites, the braconids Peristenus pallipes (Curtis) and Leiophron uniformis (Gahan), and an egg parasite, the mymarid Anaphes ovijentatus (Crosby and Leonard), are widespread and common enough to be possible candidates for augmentative releases.

Peristenus pallipes occurs over much of the United States as a parasite of Lygus lineolaris, but it has not been reported from the Southwest (Clancy and Pierce, 1966). Leiophron uniformis, the only hymenopterous parasite of Lygus spp. nymphs reported in the Southwest, is also found in low numbers from the Midwest, into Canada, and eastward to New Jersey and Delaware. The egg parasite Anaphes ovijentatus has been reported from such widespread areas as the Southwest, New York, Indiana, Louisiana, and California (Clancy and Pierce, 1966; Stoner and Surber, 1969; Sillings and Broersma, 1974). In addition to these native parasites, Peristenus stygicus Loan, imported from Europe, may be an excellent candidate if initial establishment is followed by additional augmentative releases.

The effectiveness of augmentative releases depends not on the long-term suppression of Lygus spp. but on short-term reductions in populations. These reductions will be effective if they reduce the movement of Lygus spp. from alternate host plants to crops where they cause considerable damage. In the case of L. hesperus, reduction of the first two generations on alfalfa in the spring should eliminate several insecticide applications later on cotton, which would have disrupted the entire beneficial complex there. This would save the cotton grower money by reducing the need to control Lygus spp. and other secondary pests.

REARING

Successful augmentation of Lygus spp. parasites depends on the timely availability of sufficient numbers of these parasites. Efficient and highly cost-effective methods will be needed to meet this goal. At present, few insect parasites have been reared outside their host. We must, therefore, still rely on rearing systems that begin with efficient production of living hosts.

In the past, most Lygus spp. were reared on green beans, Phaseolus vulgaris L. (Beards and Leigh, 1960), or combinations of green beans with other foods such as heat-killed larvae of the beet armyworm, Spodoptera exigua (Hübner) (Bryan et al., 1976). Rearing systems using Lygus spp. produced by these methods as hosts have been described for parasites of mirid nymphs, Peristenus stygicus (Van Steenwyk and Stern, 1976) and Leiophron uniformis (Debolt, 1981), and for the parasite of mirid eggs, Anaphes ovijentatus (Stoner and Surber, 1969). The quality and quantity of parasites and their hosts produced by these methods vary greatly with changes in the quality and availability of the mirid's food sources. Unfortunately, during late

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winter and early spring, when parasite cultures should be increased, green beans are at their lowest availability, poorest quality, and highest price. This often requires a shift to other even more expensive and less satisfactory foods.

Only recently has Debolt (1982) reported the first artificial diet suitable for continuous rearing of any Lygus sp. Improvements in rearing and feeding techniques (Patana, 1982; Debolt and Patana, 1985) have allowed greatly increased production of L. hesperus nymphs and eggs for parasite production. At the Biological Control of Insects Laboratory, Tucson, Ariz., we routinely expose over 38,000 L. hesperus nymphs per week to P. stygicus and L. uniformis, using only the excess produced by the laboratory host culture. In addition, the egg parasite A. ovijentatus has been shown to readily attack and develop well in eggs laid in synthetic membranes by artificial diet-reared L. hesperus (Jackson, 1982). Another major target species, L. lineolaris, has recently been successfully adapted to rearing on the artificial diet, though initially its reproduction was very poor. The effects of such severe laboratory selection on production or effectiveness of parasites have not been studied.

Efforts are continuing to improve the rearing procedures for parasites of Lygus spp. eggs and nymphs. Although present methods are sufficient to rear several thousand individuals of L. uniformis, P. stygicus, and A. ovijentatus per week, large-scale field testing will require the development of mechanization and automation techniques to increase parasite production.

RELEASE

The history of parasite releases to control Lygus spp. in North America has been summarized in this publication by Coulson (p. 1), Craig and Loan (p. 48), and Day (p. 20). Most releases have been of small numbers of imported parasites, and the results have not until now been published. Clancy and Pierce (1966) attempted near Riverside, Calif., in 1964 to colonize Peristenus pallipes collected from New Jersey, and they achieved some initial parasitization. Van Steenwyk and Stern (1977) reared and released a large number of P. stygicus adults in an alfalfa plot in the San Joaquin Valley of California from May through August 1973. In their study, the alfalfa was strip-cut and the cutting cycle was greatly lengthened from 30 to 60 days in order to increase the number of available Lygus. A low rate of parasitism was achieved during 1973, and the parasites were recovered in lower numbers during the next two summers. In neither instance was any attempt made to augment the parasite populations after the initial release period.

To make efficient use of parasites in augmentative releases, we need to develop release techniques that will improve the released parasite's effectiveness and survival in the field. The hymenopterous parasites of Lygus spp. nymphs can be released as adults, cocoons, or as larvae in parasitized hosts. Only adult releases have been reported, and this is usually the only procedure feasible for the immediate release of foreign material. Unfortunately, studies have not been made of the behavior of the released parasites. Such knowledge might provide clues to the timing and procedures for release. Thus, we have little knowledge as to whether the parasites begin searching for hosts, mate, leave the area, or fly to the nearest attractive nectar source. Also, we can only guess at the best time of day for adult parasite release. With the advent of improved rearing techniques, we now have available the needed numbers of certain parasites to experimentally study these factors. In addition, we can determine the potential for release of parasitized hosts or parasite cocoons or both. Successful suppression of Lygus spp. populations possibly may require release of two or all three parasite stages to provide a continuity of parasites.

Rearing procedures being developed for egg parasites may eventually allow their release in large numbers. Releases of

egg parasites, either as adults or in the host eggs, could be aimed at periods when host nymphs are not yet available.

Disruption of cultivated hosts of Lygus spp. by harvesting and cultural practices often produces an extremely unstable environment, and variable populations of both pest and beneficial insects result. Several studies have indicated higher and more stable populations of parasites of Lygus spp. on weeds, even when mixed with the cultivated host (Streams et al., 1968; Sillings and Broersma, 1974; Lim and Stewart, 1976; Graham and Jackson, 1982). Given this information, release of parasites on weed hosts, especially with small numbers of foreign parasites, may ensure more rapid and positive colonization. This could in turn provide material for later rearing and augmentation efforts.

EVALUATION

The importance of evaluating the effectiveness of natural enemies with studies that include experimental checks in paired comparative plots has been pointed out by DeBach et al. (1976). This is especially true in evaluating the short-term rapid effects we should expect from augmentation programs.

DeBach and Huffaker (1971) discussed three methods of evaluating the effectiveness of natural enemies--addition, exclusion or subtraction, and interference. The first two are most likely to be useful in assessing the benefits of augmenting parasites of Lygus spp.

The last method, interference, has been used mostly with pests that occupy discrete units of habitat such as trees. The insecticide interference method may, however, be applicable when the dispersal range of the parasite is known. The greatest difficulty with using this technique for Lygus spp. is that this pest is preyed on by a complex of natural enemies. Thus, unless an insecticide is highly specific against the parasite, it would be impossible to determine the actual causes of pest density changes.

The use of cages to exclude the parasites from certain units may provide one of the best methods to utilize the numbers of parasites we currently can produce. Leigh and Gonzalez (1976) used this technique effectively to study various predator species attacking L. hesperus on cotton. Lygus hesperus females were caged on cotton plant terminals for a limited time in large field cages, some of which had been treated with insecticide to remove indigenous species. Predators were then introduced to some of the cages. In this way these researchers were able to separate the effects of indigenous predators from those effects due to the introduced species. Two advantages of such tests are that they can be replicated in a relatively uniform habitat such as an alfalfa field or a large wild host patch and that they require only moderate numbers of parasites. Not only would such cage tests demonstrate the effectiveness of the parasite but they could provide data on the efficiency of the parasite and help to determine the numbers needed in open field releases. These tests could provide information on the immediate effect of the released parasites, but they would not be readily adaptable to studying continuing effects due to the growth and harvesting of the host plants.

When large numbers of parasites are available, augmentative releases could be evaluated in replicated tests without the need for cages. Fields of cultivated hosts such as alfalfa are usually abundant enough in one area so that release and check fields can be replicated throughout an area. Even without knowing the dispersal abilities of the pests and parasites, it should be possible to detect the level of parasitism increase we would expect from augmentation releases. This would be especially true if releases were made during periods with low rates of natural parasitism of Lygus spp., such as during the early months of the year in the Southwestern United States (Graham et al., 1986). Monitoring could be continued throughout the season, but the effectiveness of the parasites would be

harder to determine because of migration into and out of the test fields. Weed hosts also occur throughout an ecosystem in patches, which could serve as treated and check plots. Since weed patches are generally smaller than fields of cultivated hosts, they would require fewer parasites and might be even easier to replicate.

Eventually the effectiveness of parasite releases will have to be evaluated on crops over a relatively wide area. This is true whether the object is to attack the *Lygus* spp. on reservoir hosts to reduce their movement into valuable crops or to reduce the population directly on such crops. Adequate replication of such wide areas is almost impossible to achieve. Success or failure of these types of releases over a period of years will determine the effectiveness of the system.

As *Lygus* spp. infest a wide range of both cultivated and wild host plants and the area covered by certain wild hosts cannot be determined accurately in a large ecosystem, intensive sampling of all hosts will be impossible. The situation becomes much more difficult when attempting to estimate populations on the diverse hosts of *Lygus* spp., hosts that vary widely in their growth habits. Studies covering large numbers of host plants, such as those carried out by Graham et al. (1986) that provide host range and yearly population trends, should pinpoint the major sources of *Lygus* spp. adults. Quantitative sampling of these hosts, as well as of the crops we seek to protect in an ecosystem, should provide adequate data to assess the impact of augmentative releases. In addition, such sampling of major hosts will also provide data that can be used to construct life tables of *Lygus* spp. on these hosts. Studies on these life tables for critical host plants will greatly aid in assessing the importance of the various natural enemies in regulating *Lygus* spp. populations.

Both in surveys for native parasites and in attempts to evaluate parasite introductions, *Lygus* spp. nymph and adult samples have been obtained by using sweep nets (Clancy and Pierce, 1966; Hormchan, 1977) or D-Vac suction samplers (Van Steenwyk and Stern, 1977). Although both methods have advantages and disadvantages, they provide rapid sampling of *Lygus* spp. and their parasites. When the proper preliminary work is done to establish uniform sampling techniques for use on the various important *Lygus* spp. host plants, these methods should provide population estimates accurate enough to evaluate parasite augmentation programs.

Determination of the proportion of *Lygus* spp. parasitized is usually done either by dissection or by rearing the host until parasite emergence (Clancy and Pierce, 1966; Loan, 1974; Van Steenwyk and Stern, 1977; Graham et al., 1986). Dissection of nymphs provides the most accurate estimates of the proportion of hosts parasitized, since the results are not biased by differential mortality between parasitized and unparasitized hosts during handling and rearing. Nymphs can be dissected live if numbers are small, and larger numbers can be frozen for later dissection (Day, see p. 25). Nymphs can be directly examined rapidly, and probably rearing should only be used when personnel cannot handle the number of nymphs or when adult parasite or host identification is required. When nymphs are reared, the proportion parasitized should be based only on those that survive until parasite emergence (number adult bugs plus number of parasite larvae and cocoons) to eliminate from the estimate those that die of unknown causes (Debolt, 1981).

Since mirid eggs are inserted into plant tissues, it would be very difficult to directly determine parasitism by dissection. Estimates of the proportion parasitized can be made by counting mirid eggs in plant stems with the aid of a dissecting microscope and holding samples of plant stems containing eggs for emergence and identification of mirids and their parasites as described by Graham et al. (1984, 1986).

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QUARANTINE PROCEDURES FOR IMPORTED PARASITES OF *LYGUS* SPP.

By G.L. Snodgrass and L.R. Ertle[1/]

Shipment of exotic parasites of Lygus (Heteroptera: Miridae) spp. to a quarantine facility in the United States requires prior approval and permits issued by the USDA, Animal Plant Health Inspection Service, Plant Protection and Quarantine (APHIS, PPQ). Approval by the State agricultural agency where the quarantine facility is located also is required. There must be coordination between the shipper and this facility as to timing, correspondence, packaging, routing, and so forth. In addition, the quarantine facility must ensure that the proper numbers and life stage(s) of the intended host(s) are available for testing when the parasites are received. An excellent discussion of the procedures for shipping parasites to a quarantine facility is found in Jones et al. (1984). Additional information on packaging live material for shipment is in Boldt and Drea (1980).

The United States has 20 Federal and State quarantine facilities available for the importation of a wide variety of biological material (Knutson et al., 1982). The Beneficial Insects Research Laboratory, the USDA, ARS quarantine facility in Newark, Del., has been the main facility for importing parasites for use in controlling Lygus spp. Many of these parasites were collected in Europe and propagated at the ARS European Parasite Laboratory in Sevres, France. The ARS research quarantine facility in Stoneville, Miss., is involved in evaluating parasites collected in Africa for release against Lygus spp.

ROLE OF THE QUARANTINE

The role of a quarantine facility on receipt of any culture of an exotic parasite species is to check the culture for unwanted plant material, to positively identify the parasite, and, when advisable, to subsequently ship strong, viable specimens. If the biology of the parasite is well known and rearing methods for it have been established, then the quarantine facility may only need to forward the culture to its final destination. The quarantine facility could also perform host range studies or increase the numbers of cultures prior to their release from quarantine. A quarantine facility can also receive a culture of a parasite species, usually in limited numbers from field-collected hosts, whose biology is not well known. In this instance, the quarantine facility must try to simultaneously evaluate the parasite against a targeted Lygus sp. and increase the numbers of parasites.

Since information on the basic biology of the parasite needed to develop rearing methods for the particular species is usually lacking, knowledge from rearing a closely related species of parasite must be used. Consequently, a proper evaluation of the parasite may not be obtained. If a viable colony of the parasite is established in quarantine using the targeted Lygus sp. host, then additional data can be obtained on rearing methods, host efficacy, and host range. This information is critical for propagating the parasite and determining when and if it should be released from quarantine.

PROPAGATION OF TARGET AND NONTARGET HOSTS

A quarantine facility must be able to rear not only the intended Lygus host but other insect species used in related host range studies. Species of Lygus usually can be successfully reared on one of their plant hosts such as green beans, Phaseolus vulgaris L., which can be purchased throughout the year. Lygus lineolaris (Palisot), L. hesperus Knight, L. desertinus Knight, and L. elisus Van

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Duzee all can be reared on green beans (Beard and Leigh, 1960; Butler, 1970; Mueller and Stern, 1973; Parrott et al., 1975). Several artificial diets have been tested for suitability in rearing L. lineolaris and L. hesperus (Landes and Strong, 1965; Auclair and Raulston, 1966; Vanderzant, 1967; Strong and Kruitwagen, 1969); however, the only artificial diet on which any mirid has been reared continuously is that developed by Debolt (1982) for L. hesperus.

In general, Lygus spp. can be reared between 15° and 30°C, at a day length of 14 hours or longer to prevent reproductive diapause, and at a relative humidity of 50-60 percent. The most satisfactory rates of development usually occur from 25° to 30° (Ridgway and Gyrisco, 1960; Leigh, 1963; Champlain and Butler, 1967; Strong and Sheldahl, 1970; Butler, 1970; Butler and Wardecker, 1971; Mueller and Stern, 1973; Khattat and Stewart, 1977). The rearing of related beneficial species of Hemiptera for host range studies is often more difficult than rearing Lygus spp. Colonies of a few predaceous species, such as Geocoris punctipes (Say) (Cohen and Debolt, 1983) and Orius insidiosus (Say) (Isenhour and Yeargan, 1981), can be maintained under laboratory conditions.

The eggs or nymphs of other beneficial species can be collected from the field for exposure to the parasite being tested, but care must be taken to ensure that they are not already parasitized by native parasites. This can be accomplished by holding part of the field-collected eggs or nymphs separately for observations of native parasite emergence. Field-collected nymphs of predaceous Hemiptera often can be reared by providing them with a water source and lepidopterous eggs or larvae for food, which expands the rearing program in order to maintain a supply of the required hosts.

REARING NYMPHAL AND EGG PARASITES

Species of Peristenus and its closely related genus Leiophron comprise most of the known nymphal parasites of Lygus spp., whereas all known egg parasites of Lygus spp. are mymarids in the genera Anaphes, Erythmelus, and Polynema (CIBC, 1979). Nymphs or eggs of Lygus are often exposed for parasitization by placing them in cages with adult male and female parasites. Cages vary in size and are commonly ventilated cardboard or plastic containers.

Adult parasites are provided with a water source and usually fed honey or a honey-sucrose mixture applied to the sides of the cage. A fan may be placed near the cage since the movement of air through the cage may stimulate mating or oviposition (Hormchan, 1977; Porter, 1979). To ensure that female parasites are mated, cocoons or parasitized eggs can be held individually in gelatin capsules until adult emergence. Emerged parasites are sexed, then paired and observed for mating. Most species of Peristenus diapause within a cocoon in the soil and mate soon after emergence (Bilewicz-Pawińska, 1971; Drea et al., 1973; Van Steenwyk and Stern, 1976; Hormchan, 1977). The use of mated female parasites is critical because all known Lygus spp. parasites are arrhenotokous, or produce only male progeny if unmated. The occurrence of diapause complicates rearing efforts, since it lengthens the time required to increase a parasite culture in numbers. It also makes field releases of the parasite more difficult, since the parasite must emerge when hosts in the field are in the proper life stage for parasitization.

BIOLOGY STUDIES

If a parasite attacks the Lygus nymph or egg to which it is exposed and progeny develop successfully, then studies should be made to determine the number of nymphs or eggs parasitized per female. Other criteria such as the sex

ratio of the offspring, the occurrence of diapause, and the longevity of the adult parasite are very useful in evaluating a parasite species prior to its release or in propagating for release. In some cases, parasitization apparently occurs, but no parasite progeny are produced; dissection of the host after parasitization may be necessary to determine host resistance mechanisms, such as encapsulation.

Results of laboratory studies can be affected by environmental conditions under which the host is exposed and reared, age of the host egg parasitized, density and instar of the host exposed, and diet of the adult. For example, Van Steenwyk and Stern (1976) found that the number of progeny of *Peristenus stygicus* Loan decreased when *Lygus hesperus* was parasitized in later instars, although a higher percentage of the progeny instars were females. Adult longevity was inversely related to temperature, and at a day length of 12.75 hours nearly all offspring entered diapause. Debolt (1981) found that the maximum progeny per female of *Leiophron uniformis* (Gahan) were obtained when 75 nymphs of *L. hesperus* were exposed per female parasite; no increase in female offspring occurred when more than 50 hosts per female parasite were exposed. The greatest number of progeny per female parasite was produced when hosts in instars two and three were attacked. Stoner and Surber (1969, 1971) studied the mymarid *Anaphes ovijentatus* (Crosby and Leonard) and found that fewer parasites were produced in *Lygus* eggs as the age of the exposed egg increased. The rate of development and adult longevity for both sexes were temperature dependent.

The time that *Lygus* spp. nymphs or eggs should be exposed to a parasite for parasitization varies. Van Steenwyk and Stern (1976) exposed *Lygus hesperus* nymphs to *P. stygicus* for 48 hours, whereas Debolt (1981) found that there was no increase in progeny of *Leiophron uniformis* per female parasite when *L. hesperus* nymphs were exposed for periods longer than 1 hour. After exposure, *Lygus* spp. eggs or nymphs are removed from the cages and held for parasite emergence. Nymphs are often held in cardboard cartons with a substrate in the bottom for parasite pupation once the larvae leave the host nymph or adult. Depending on the species, larvae of *Peristenus* and *Leiophron* can emerge from older nymphs or adults (Brindley, 1939; Loan, 1965; Drea et al., 1973; Loan and Craig, 1976; Hormchan, 1977; Debolt, 1981). The substrate provided for pupation is commonly a layer of vermiculite or layers of black felt. Since some species of *Lygus* are facultative predators (Wheeler, 1976), the pupation substrate is usually separated from the *Lygus* nymphs by a wire screen or a similar device that allows the parasite larvae to crawl through but that excludes the *Lygus* nymphs.

Parasitized eggs may be held in petri dishes. Cocoons of nymphal parasites can be removed from the pupation substrate and held separately or left undisturbed in the substrate until emergence. Cold storage at approximately 10°C for varying periods of time may be required to break diapause. Some parasites, such as a Turkish strain of *P. stygicus*, do not undergo diapause under laboratory conditions (Drea et al., 1973).

HOST RANGE STUDIES

In nature most parasites attack several different host species. In the laboratory, the barriers of time and space that separate potential hosts and parasites in nature are absent (Doutt, 1959). Consequently, host range studies can be misleading since parasitization of a species in the laboratory may not occur in nature. Information on the life cycle and host range of a parasite in its native country is very useful in determining whether or not host range studies must be done in quarantine and in choosing the potential hosts to be tested. Host range studies should be conducted when little is known about the native host range.

The beneficial insects to be screened in quarantine can be selected by considering

the host range of closely related species of the parasite, if this information is available. Consideration also must be given to the most abundant hemipterous predators that occur in the intended release area of the parasite, and one or more of these predators should be screened for parasitization by the exotic parasite. The presence of alternate mirid hosts in the release area can be critical to the establishment of an exotic parasite of *Lygus*. Consequently, the mirid fauna in an intended release area should be known. Mirid species such as those in the genera *Ceratocapsus*, *Pilophorus*, *Deraeocoris*, *Phytocoris*, and *Hyaliodes* are predaceous (Kelton, 1980) and parasitism of them is undesirable. Therefore, host range studies should also include some of the most abundant predaceous and phytophagous species of Miridae found in the intended release area. A good example of a host range study where predaceous and phytophagous species of Miridae were screened for parasitism was performed by Jackson and Graham (1983) using the native mymarid egg parasite *Anaphes ovijentatus*.

Two methods can be used to expose nontarget hosts to exotic parasites in quarantine. In a no-choice method, the parasite is exposed only to the nontarget host, using the same methods for exposing the eggs or nymphs of the intended *Lygus* spp. host. If parasitization of the nontarget host occurs in a no-choice test, then additional tests can be performed where the intended *Lygus* host and nontarget host are exposed to the parasite simultaneously to determine host selection preference.

RELEASE OF PARASITE FROM QUARANTINE

The decision to release an exotic parasite of *Lygus* from quarantine is usually made by the quarantine officer involved and requires the permission of the appropriate State and Federal officials through the use of PPQ Form 526. This decision is made after a careful examination of all the available data relating to the parasite and its potential host range.

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SUMMARY AND RECOMMENDATIONS

By H.M. Graham[1]

This publication was prepared by members of a Coordinating Subgroup on Biological Control of Lygus and Other Mirids that was established in 1980 under the USDA, ARS, Working Group on Natural Enemies. Its purpose is to review, update, and consolidate information on the pest status, general biology, taxonomy, and efforts toward the biological control of two genera of mirids, Lygus and Adelphocoris, in North America. The Lygus spp.--mainly L. lineolaris (Palisot) in the East and L. hesperus Knight in the West--are indigenous pests of a wide variety of seed, fruit, vegetable, fiber, and forage crops, causing significant economic losses by direct damage, costs of control measures, and indirect effects of pesticide applications on nontarget organisms, especially entomophagous arthropods and pollinators. Adelphocoris lineolatus (Goeze), an introduced species, is mainly a pest of alfalfa in the Northern United States and Canada.

Indigenous parasites attacking Lygus spp. include the mymarid Anaphes ovijentatus (Crosby and Leonard), which attacks the eggs in a variety of habitats, with rather high levels of parasitism in some instances. Three indigenous species of braconids attack Lygus spp. nymphs. Peristenus pallipes (Curtis) is reported from Lygus lineolaris (also A. lineolatus) on alfalfa and weeds, P. pseudopallipes Loan from L. lineolaris on Erigeron spp., and Leiophron uniformis (Gahan) from L. lineolaris, L. hesperus, and L. elisus Van Duzee on various crops and weeds. Levels of parasitism by the braconids are generally low, but high levels may be reached in some instances. Tachinids of the genus Alophorella emerged from adults of L. lineolaris, L. elisus, and L. hesperus from alfalfa and weeds, but the levels of parasitization are low. Nematodes have been found infesting L. lineolaris in a few instances, and some Lygus spp. have been reported killed by fungi.

Efforts to establish parasites of Lygus spp. from Europe in North America have been unsuccessful. Most of the efforts have involved the braconid Peristenus stygicus Loan, and although parasitized nymphs were recovered after parasite releases, the parasites failed to become permanently established. Smaller releases of P. digoneutis Loan and P. rubricollis (Thomson) were unsuccessful also. Likewise, releases of P. adelphocoridis Loan against Adelphocoris lineolatus have not resulted in parasite establishment.

Explorations in southern Asia failed to yield any parasites of Lygus spp. other than an egg parasite with a broad host range. A study in Egypt revealed a species of Telenomus (family Scelionidae) parasitizing high percentages of eggs of Taylorilygus pallidulus (Blanchard) on Matricaria chamomilla L. None of these parasites were imported.

Surveys in South Africa in 1981 found two egg parasites, Chaetostricha spp. (family Trichogrammatidae) and Telenomus spp. (family Scelionidae), and two nymphal parasites, Peristenus nigricarpus (Szepligeti) and P. praetor (Nixon) (family Braconidae), attacking the mirid Lygidolon laevigatum Reuter on Acacia mearnsii De Wild. in Natal Province. The nymphal parasites were shipped to the Stoneville, Miss., quarantine facility, but only three survived shipment, and these failed to reproduce. Additional collections and shipments of these braconids were made in 1982, and two generations of P. praetor and one of P. nigricarpus were produced on Lygus lineolaris in quarantine, but no sustained culture was obtained. Collections were made in Kenya in 1983, and nymphal parasites of Taylorilygus spp. were obtained. Eight adult P. nigricarpus and an undescribed

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Leiophron sp. were recovered in quarantine. Two generations of P. nigricarpus were reared on Lygus hesperus, but no sustained culture was obtained. In late 1985, a shipment of the undescribed Leiophron sp. and P. nigricarpus was received at Stoneville from the Commonwealth Institute of Biological Control in Kenya and is being reared successfully on L. hesperus and L. lineolaris.

The research to date on the biological control of Lygus spp. and Adelphocoris lineolatus has not yielded successful systems for suppressing populations of the pests, but it has produced a vast amount of basic information on the hosts and natural enemies that is needed for the development of such systems. Future research must build on this information until successful systems can be devised. In the area of classical biological control, the successful culturing of the unidentified Leiophron sp. from Kenya in Lygus hesperus and L. lineolaris provides another species of parasite that might fit into our agricultural systems, but a great deal of basic research must be done before its potential can be determined. Some other areas of the world remain to be explored for other parasites that might have potential for use in North America. These include northeastern Asia, U.S.S.R., and Latin America. Efforts should be made to initiate these explorations. Efforts to use European parasites against A. lineolatus, an introduced species from Europe, should be continued.

Research directed toward the development of inoculative or augmentative release of parasites against Lygus spp. in certain situations should continue. A rearing system for L. hesperus based on an artificial diet has made rearing the host and its parasites much more reliable. However, improvements need to be made, especially for rearing the parasites, and the system should be enlarged. A great deal of information on the behavior and biologies of the parasites is needed so that methods can be developed to use them effectively against the pests. When these procedures are accomplished, their feasibility must be tested.

The research should be expanded to include other important mirid species. The cotton fleahopper, Pseudatomoscelis seriatus (Reuter), is a possible candidate. Besides basic information on the ecology and biological control of the pest, exploration for exotic natural enemies attacking related genera might be started.